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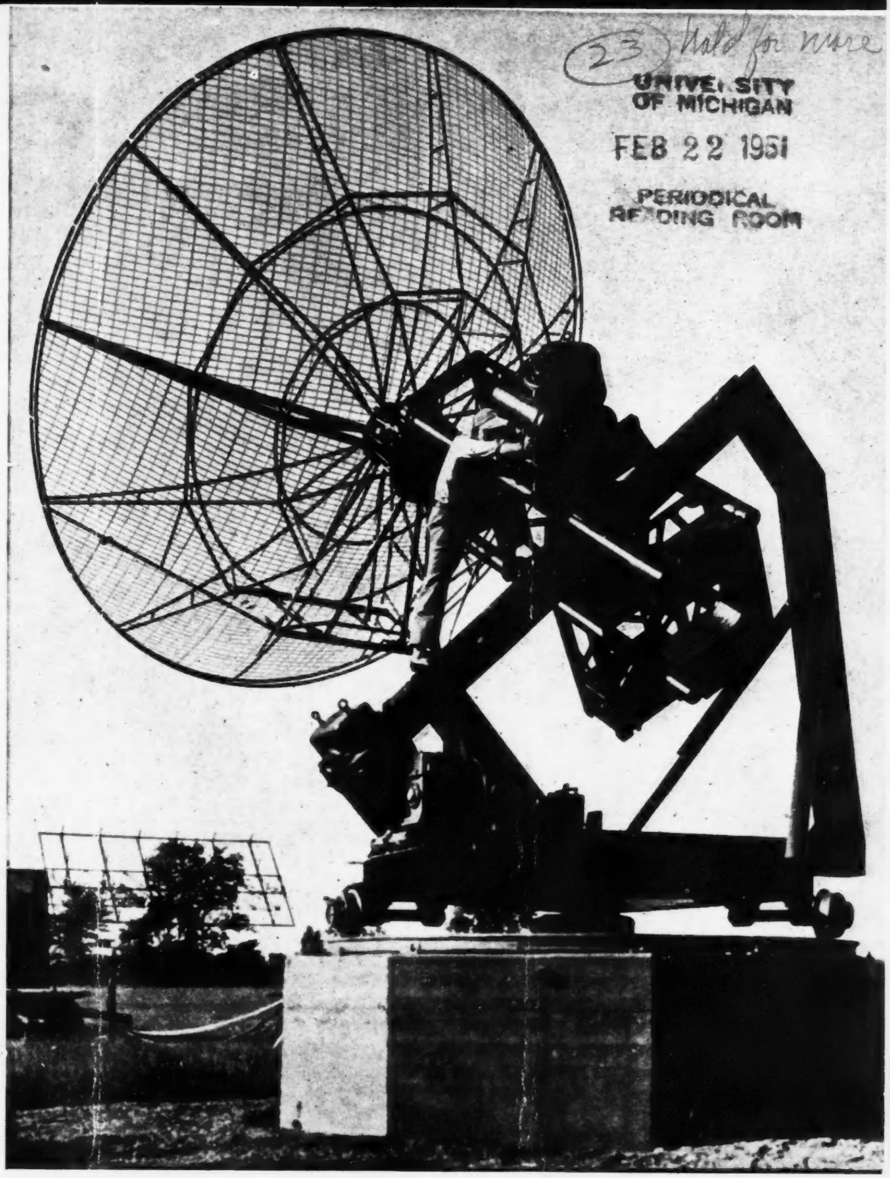

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THE MAGAZINE OF SCIENTIFIC PROGRESS

January, 1951 Vol. XII. No. 1

Editor WILLIAM E. DICK, B.Sc., F.L.S.
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The Progress of Science

The New Burnham Scale and Science Teaching

THE new Burnham Scale which will increase the pay of teachers in April is now almost certain to be adopted. This was virtually settled by the delegate meeting of the National Union of Teachers held at the end of November, for the passing of a resolution by the meeting was equivalent to instructing the N.U.T. members of the Teachers' Panel of the Burnham Committee to endorse the proposed salary scales. This Panel has 26 members and sixteen of them represent the N.U.T., with the inevitable result that the views of the other teachers' associations represented on the panel count for very little. Any policy adopted by the N.U.T. is virtually bound to carry the day at meetings of the Panel.

As a result of the publicity given to the N.U.T. acceptance of the proposed Burnham Scale, the public has been given the impression that the proposals are acceptable to the teaching profession in general. Now though it is obviously true that the proposed scale is an improvement over the existing scale, it is far from satisfactory in some respects. The new scale increases teachers' salaries by £75, also increases the allowance to graduates from £30 to £60. (In the case of women teachers the increases are less.) But with this slight easing of the impecunious position of the schoolmaster, the serious anomalies of the system, so deleterious to higher education, are to remain.

The same scales are to continue to apply to all teachers in Primary and Secondary (Grammar, Technical and Modern) Schools. In spite of the shortage of specialists there is again to be no inducement to graduates to teach at a high academic level. The alleged inducement to recruits of high qualifications is that they may qualify for a 'special responsibility' allowance (hitherto between £40 and £150). Each school has a quota of these allowances which go to the teachers in charge of certain subjects. But in most schools, a subject such as science will carry only one such allowance which goes to the senior master in the subject. Thus, although several competent scientists are necessary in a Grammar School to teach chemistry, physics, and biology to university standard, often only one 'special responsibility' allowance is paid. But if the less fortunate scientists go to Modern Schools to teach general science at an elementary standard they are very likely there to gain the allowances.

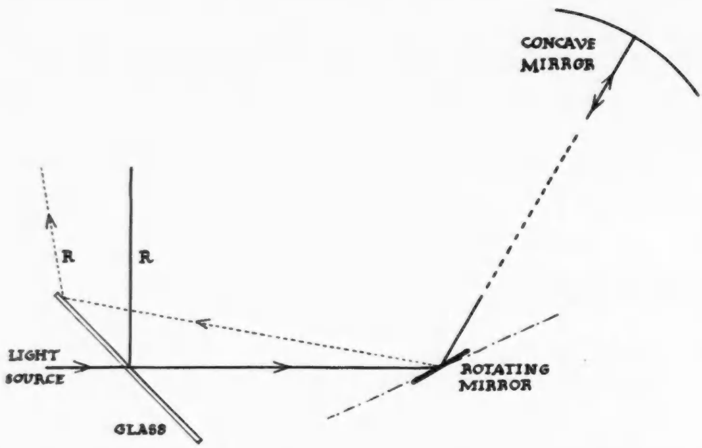
These 'inducements' thus tend to attract the specialists away from Grammar Schools, since they are likely to be paid more for teaching at a lower level in Modern Schools. The new proposals will allow this drift to continue, and the graduates who should be preparing the 18-year-olds for their university courses will still be attracted away to teach elementary work to the less able 14-year-olds.

Responsibility allowances are thus worse than useless as an attempt to keep up high academic standards in Grammar Schools. Only a Grammar School allowance, or a specialist allowance for all those who teach at a high academic level, is likely to provide the future undergraduates with the teachers they now need.

How Fast Does Light Travel?

THE news that Dr. L. Essen of the National Physical Laboratory has established a new value for the speed of light in free space is a reminder that the determination of this physical constant has been important to scientists for several centuries. Indeed, the very fact that there is a speed at all in free space—that light transmission, in other words, is not instantaneous—was a revolutionary seventeenth-century idea. Had this speed been measurable at the time, nearly two centuries of controversy between supporters of the corpuscular theory and of the wave theory of light propagation would have been avoided, for a cardinal point of the corpuscular theory was that light travelled faster in glass or water than in air—only on this assumption could the observed truth of Snell's law of refraction be 'proved' theoretically. When at length it was shown experimentally that light actually travelled more slowly in water than in air, the old crude corpuscular theory had to be abandoned.

Galileo made the first recorded attempt to measure the speed of light. Two observers, each with a lamp that could be obscured, were stationed three miles apart. Observer *A* uncovered his lamp and started a clock. Observer *B* uncovered his lamp when he saw the light from *A*. Observer *A* stopped his clock as soon as he saw the light from *B*. It was hoped that the time taken for light to travel from *A* to *B* and back again might be measured with the clock,



Schematic diagram of Foucault's method (1850) for finding the speed of light. Distance from concave mirror to rotating mirror was 13½ feet. The dot-and-dash line suggests the position taken up by the rotating mirror in the time taken for light to travel to the concave mirror and back, giving the reflector ray shown in dotted line. The shift of image measured is that caused by the change from R to R¹.

but Galileo found that when the distance between *A* and *B* was reduced there was no significant reduction in the time-interval measured; and so he failed to get any measurement for the speed of light. Today it is easy to appreciate that the time taken for either observer to make a decision and operate a clock or shutter—his 'reaction-time', as it is now called—was thousands of times greater than the time taken by light to travel from *A* to *B*; even when *A* and *B* were three miles apart, the time of double transit of the light was less than a thirty-thousandth of a second, whereas the reaction-time is to be measured in tenths of a second.

The first demonstration that light had a finite speed in 'empty' space came from the Danish astronomer Römer in about 1675. He utilised the eclipses of Jupiter's satellites. He even calculated a value for the speed, but this depended on an assumed diameter of the earth's orbit round the sun. His result was of the right order numerically, but few people were willing to take it as correct.

The first experimental determination by normal terrestrial methods did not come until 1849. Two names, both French, must be associated with the work, though one of them has chronological precedence—A. H. L. Fizeau published his first result in 1849, and J. B. L. Foucault showed in 1850 that light travelled more slowly in water than in air.

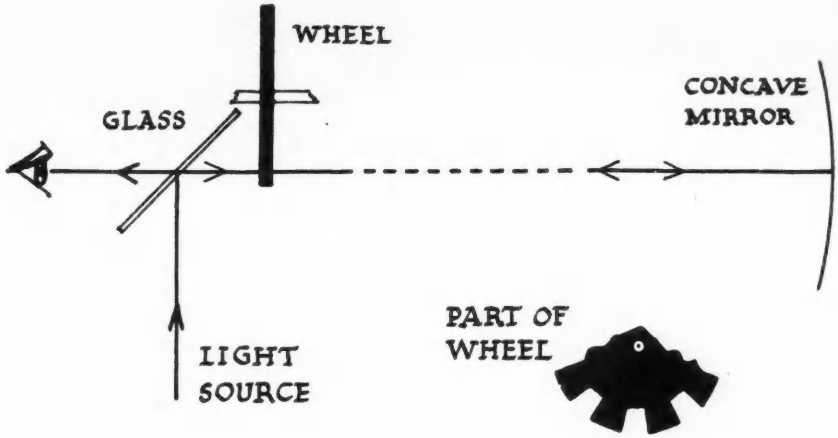
The methods used by the two men have been illustrated in every standard text-book on light. Both of them devised ways of measuring very small intervals of time by means of rapid interrupting motion caused by rotation, Fizeau with a toothed wheel, and Foucault with a rotating mirror. Both of them arranged their optical systems to allow the transmitted light to be reflected over a distance—Fizeau worked with about 5 miles, Foucault with 13½ feet—over the same optical paths and thus enable the observer to be at the transmitting end and receiving end simultaneously. Fizeau's method depended on the interruption of the reflected beam by a tooth that had taken the place of a gap on the wheel, whereas Foucault made use of the slight difference in position of the image when reflected from a mirror rotating very fast. For almost a century all the methods of measuring the speed of light were modifications of the principles used either by Fizeau or Foucault.

It can be said at once that the value found by these two scientists still stands for qualitative discussion at the level of, say, the school classroom. This value in simple figures is 300,000 metres per second, which is roughly equivalent to 186,000 miles a second.

Two developments made a really accurate determination very desirable. One was Clerk Maxwell's argument that electromagnetic disturbances would travel in free space with the speed of light, with the added complexity that units derived from electrostatics bore a relationship to units derived from electromagnetics, this relationship being the speed of light! The second development was Einstein's postulate that the speed of light *in vacuo* was a universal constant, the maximum speed conceivable anywhere in the universe. In other words, any statement purporting to deal with a speed greater than that of light is meaningless.

These developments probably account for the fact that A. A. Michelson, a German who became an American citizen and won a Nobel prize in 1907, spent many years on experiments for determining the speed of light and died before the finally accepted determination made with his apparatus was obtained in 1935. This value can therefore be called the Michelson value. In 1941 R. T. Birge collated the available evidence from the Michelson experiments and others, and gave the most probable speed of light *in vacuo* as 299,776 $\pm$4 kilometres per second. Ignoring the range of error, this value is equivalent to 186,271 miles a second.

The point now arises—and it can hardly be over-emphasised—that there is no such thing as exactness in practical measurement. When, for example, a statement is made that something is 10 inches long, this is only an approximation; the accuracy of the figure depends on the actual limits to which the length is measured. A carpenter, for instance, would be no nearer than his eye could judge on a ruler, whereas a standardising metrologist could work to a limit set by the wave-length of light by the method of optical interferometry that Michelson invented. The tolerances of measurement in practical engineering have greatly diminished in the past half a century, so that a tolerance of a tenth of a thousandth of an inch in certain measurements is now standard engineering practice. Any



Simplified diagram showing principle of Fizeau's method (1849) for measuring the speed of light. Distance from concave mirror to wheel was just over 5 miles. Inset is a part of the face of the the wheel to suggest the teeth and gaps.

figure claiming precision must therefore be stated with its limits of accuracy.

It was important in 1941 that the accepted value should be accurately known, for the calibration of radar instruments and the accuracy of radar navigational methods depended on it, and it was while he was engaged on such work that Dr. Essen felt doubts about the accepted value. He was using a resonance method of measuring the wave-length of centimetric waves. This method depends on the fact that such waves travelling along a cylindrical wave-guide, or conducting tube, are reflected, and when the length of tube is an exact number of half-wave-lengths, the energy of the wave is at a maximum. (This statement is an over-simplification, as every radio engineer familiar with wave-guides knows, but for an outline of the method it will serve.) He then looked into the methods used by previous workers for measuring the speed of light. He found that the Michelson result was calculated from the means of groups of a great number of observations; for example, means of groups consisting of some 500 measurements differed by as much as 11 kms. per second, and with some smaller groups there was a difference of 93 kms. per second. In other words, in the language of the statistician, there was a very wide 'scatter'. This raised doubts about whether the errors involved were in fact 'random' errors, for only on the assumption that errors are random is the acceptance of a mean, or average, justified, and when errors are random they are likely in a properly conducted experiment to be closely grouped round this mean. Results from another worker (W. C. Anderson) showed a difference of 67 kms. per second between the means of groups of about 200 measurements. Dr. Essen concluded that the fact that the final Michelson result and the final Anderson result were in close agreement was therefore misleading, and he decided on a research to determine the speed of light by using radio waves and methods of measurement of the greatest obtainable accuracy.

His method was that of the resonance wave-meter already mentioned. The frequency of the waves used, a frequency derived from the National Physical Laboratory frequency standard, was measurable to a few parts in a million. The length of his conducting cylinder was measurable to a thirty-thousandth of an inch. This was his first apparatus, accounts of which were published in the *Proceedings of the Royal Society* in 1948, and it consisted of a copper cylinder of fixed length with two tiny 'aerials' of thin wire inserted in one end. A wave-length of 10 centimetres was used. The whole was put into a metal container that was evacuated all the time the experiment was in progress. In more recent work, the cylinder is some eight inches or so in length and is made of steel coated with silver. This has made more accurate machining possible. One end of the interior is adjustable and the usable length can be measured with slip gauges calibrated by optical interferometry to about one part in a million. With such an adjustable piston several lengths of resonant chamber can be used. The moment of resonance is determined by visual observation on a cathode-ray screen, either by adjusting for maximum height of vertical trace or by adjusting two vertical traces to coincidence. The procedure is to feed into the cylinder electric oscillations of 3 centimetres in wave-length, adjust for resonance, and then measure the frequency and length. A formula involving the diameter of the cylinder, the attenuation of its conducting surface, and so on, has to be used for the final calculation.

The National Physical Laboratory could be dubbed the Palace of Precision, and scientists there have a very different attitude to measurement from that of scientists outside. Dr. Essen's latest result for the speed of radio waves (and therefore of light) *in vacuo* is 299,792·5 kms. per second ± 3, and this 3 represents the *maximum* possible error, not the scatter of widely different results. Converted into a whole number of British miles, this result is 186,282 miles a second. All Dr. Essen's possible sources of error have been estimated and tabulated in his published work.

Already practical results have followed from the use of this new value, for Professor C. A. Hart of Roorkee University has stated that in radar surveying done by him in Italy in 1948 a range of 400 miles had an error of 45 metres with the old value, but an error of only 5 metres with the Essen value. No results have yet been published about the effects of the new value on calculations in nuclear physics, but the fact that the Einstein equation connecting

mass and energy involves the square of the speed of light shows that the new value may be important in such work.

Anyone with a lingering doubt about the value because it is measured with radio waves and not visible light will be reassured by recent work by Bergstrand in Sweden. Using optical methods, he obtained a result of 299,792·7 kms. per second ±0·25, which is sufficiently close to Dr. Essen's figure to suggest that in fact a new value for a universal constant has been established, a value that will have to be inserted in all tables of physical constants.

Science for the Blind

FOR the second year in succession an exhibition for the blind and partially blind was held at London's Science Museum during December. The first proved such a success that the second was made considerably larger, and consisted of a hundred exhibits arranged in twenty-five sections. There were about half a dozen exhibits, all of which could be handled by the visitors, to a section, covering such subjects as transport, printing, textiles, electrical engineering, meteorology, building, boats and aircraft.

At the entrance to the exhibition was a relief plan, each section being represented by a raised block with the name of the section on it in braille so that visitors could find their way about the gallery by reference to the plan. Each exhibit had two descriptive labels, one in braille and one in ordinary print for those who were accompanied by sighted people. (The exhibition was not open to the general public.)

Perhaps the most popular single item was the sectioned chassis of a 10 h.p. Ford Prefect car. This was on show at the special request of visitors to the last year's exhibition. By following the description of the mechanism given on the label, visitors were able to feel the action of brake, gears, clutch and the driving shaft. Models of aircraft were popular too, and so was a model of the interlocking frame of a signal box.

Some of the exhibits displayed great ingenuity on the part of the organisers. There was one section consisting of busts of famous scientists so that blind people could gain some idea of what these men looked like by feeling the features.

There was an intriguing model of a section through Westminster Hall showing the construction of the hammer beam roof; all the beams could be taken apart and fitted together like jig-saw puzzle pieces.

To show how atoms are assembled to make the molecules of such substances as carbon dioxide, water and benzene there were three-dimensional models, brass balls being used to represent the atoms and steel rods to represent the bonds between them.

In the industrial chemistry section there were skeins of different fibres, ranging from the natural ones like wool, flax and jute to the synthetic fibres—nylon, rayon and alginate—some of which might seem indistinguishable from each other to the touch of a sighted person.

In the same section the sense of smell as well as that of touch was utilised. An exhibit showing the conversion of clove oil into vanillin included clove buds and the more expensive vanilla bean, and a series of bottles containing clove oil, eugenol, iso-eugenol and vanillin each with its characteristic smell to distinguish the different stages in the process of conversion.

An item of historical interest in the printing section was a typewriter for the blind made by Mr. G. A. Hughes of Manchester Blind Asylum in 1850. A dial with raised characters was turned until the required letter was in the correct position and by pulling a lever the impression was made; a screw on the carriage controlled the spacing between the lines. In contrast were the rapid modern typewriters.

It was pleasant to notice the complete absence of any air of 'patronising' the blind. While some exhibits were quite simple, others, such as the demonstration of the movement of a pendulum clock, were of an intricacy that might confuse someone with vision if he were not mechanically minded. There was something there to interest blind people both young and old, and, what is more important, the exhibition provided evidence that other people are interested on their behalf. It is to be hoped that the success of this second scientific exhibition will prove to the organisers the merit of making it an annual event, for while it is easy enough to sympathise with the blind it is not often that there is an opportunity for helping them to share the activities of sighted people.

A National Science Centre

FOR a long time the accommodation in Burlington House, Piccadilly, has been inadequate if the Royal Society and the four other major scientific societies which are housed there are to carry out all their functions effectively. The Government has for many years recognised the principle that these societies are more than just private societies; the public derives indirect benefits from their activities, and in recognition of this fact the Government provided the accommodation in present use at Burlington House. Just how far the societies are hampered by lack of space was brought home most forcefully in a presidential address of Sir Henry Dale's to the Royal Society during the recent war. The plight of the scientific societies at Burlington House was epitomised by the particular case of the Chemical Society: when it moved into its present home its membership was 450; this figure has now increased more than ten times. It is physically possible to accommodate only a tiny fraction of the membership in the lecture room, which is bound to hamper any society of which the reading of papers on new developments is a vital function. The Chemical Society Library is about the most important collection of chemical books in London, and chemists from all over Britain use it; yet so far has that library outgrown the available space that some of it has to be stored in the crypt of a neighbouring church. The fact that a very important society like the Physical Society cannot be given any room at all in Burlington House is indicative of the gravity of the 'housing shortage' so far as British scientific societies are concerned.

It was therefore good news to hear from the Lord President of the Council that the Government is prepared to implement the long-term proposals, originated by the Royal Society, for a British Science Centre in London. The Lord President's statement was not widely reported, and therefore it is worth giving the major details of that statement. He began by stressing that it would be some years before the Ministry of Works could erect a suitable building, and then proceeded to outline the scheme for the Centre which is every bit as ambitious as any of the

advocates of a National Science Centre could have wished. Provision will be made for accommodating within the area the Patent Office and its Library, which will be modernised and extended as a first-rate central reference library on science and technology.

Suitable new quarters will be built for the Royal Society and for other leading scientific societies with their important special libraries. New offices for the Department of Scientific and Industrial Research and other Government scientific organisations will also be provided. Mr. Morrison concluded by saying that the Centre will be designed to improve facilities and contacts between scientists and users of science, both nationally and internationally. Much detailed planning remains to be done, but it may be convenient for the many interests affected to have this preliminary advance statement. He hoped to announce the selection of a site early in the New Year.

Girls from The Chorley Wood College for Blind Girls studying synthetic fibres at the Science Museum's exhibition arranged for blind persons.

DDT and Human Food

One of the most intriguing examples of the use of radio-isotopes in research has come from the Government's Pest Infestation Laboratory. Briefly, its object was to follow the fate of DDT residues upon wheat grains *after* the grain had been consumed as food. First, of course, it was necessary to prepare a sample of DDT in which one of the elements in the molecule was radioactive. The subsequent movements of the DDT residues upon grain could then be followed in animal bodies by locating and measuring the emitted radiations. It was found necessary to make a practical compromise and to use a chemical homologue of DDT instead of DDT itself. DDT has a molecule containing four chlorine atoms, one of which occupies a particularly stable position. Bromine, a sister element to chlorine, has a much more suitable radio-isotope for use in this type of research. The actual insecticide used, therefore, was identical with DDT except that the stable chlorine atom was replaced by radioactive bromine. This should not be considered to reduce the value of the results since other and earlier work has shown that this bromine analogue of DDT is closely similar to DDT in all its properties including its toxicity.

Wheat was sprayed with the radioactive insecticide. Some was then milled and baked into bread. Both the wheat and the bread were fed to hens and rabbits. In one of the series of experiments a research worker consumed 30 grams of the bread. Although only minute amounts of the insecticide were involved—for example, the bread contained only 11·2 parts per million—it was possible to follow the quantitative movements of these trace amounts by measuring the radiations emitted. In the hen and rabbit feeding tests, considerably detailed investigations were possible by killing the animals after five days and measuring the radiation from dissected organs and tissues.

Residues of the insecticide were found in all tissues examined, thus proving that substances of the DDT class are (1) not quickly eliminated from animal bodies, and (2) are widely distributed throughout the body soon after consumption. In hens fed with the grain, residues were found in the gizzard, liver, kidney, sciatic nerve fibre, heart and brain tissues; in rats fed with the bread, residues were found in the sciatic nerve fibre, brain and liver. In the single human test only 5% of the total activity in the bread consumed was eliminated in urine during the first 48 hours after ingestion.

This piece of research emphasises the toxic dangers of DDT residues upon foodstuffs, dangers which have increasingly worried thoughtful scientists in recent years. The powerful tendency for DDT traces to be retained in the body rather than to be swiftly eliminated has been neatly established. The widespread use of DDT to protect edible crops and stored grain would give rise to serious risks of cumulative toxic effects upon human or animal consumers of the food. It is perhaps no coincidence that soon after the publication of this research, farmers and flourmillers were warned not to treat wheat with DDT.

A stamped addressed envelope should accompany unsolicited articles sent to the Editor; otherwise no responsibility for their return can be accepted. Inquiries from readers seeking information on matters other than normal business matters must also be accompanied by a stamped addressed envelope. (Overseas readers should enclose an international postal reply coupon to cover return postage.)

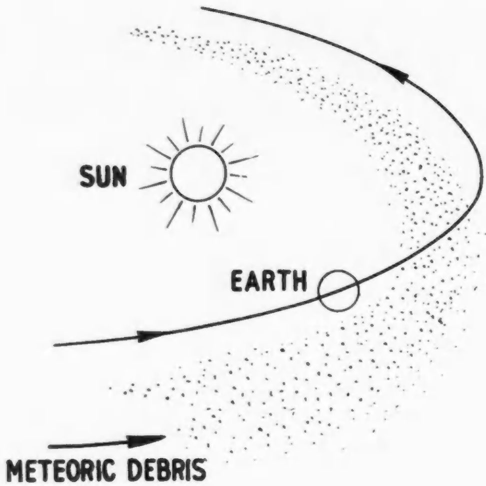


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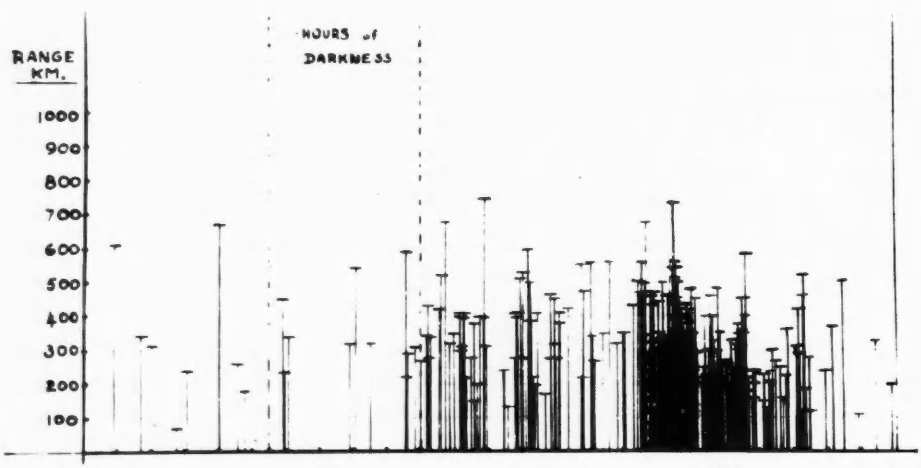
FIG. 1.—Production of a meteor shower as the earth sweeps through a concentration of debris in space.

FIG. 2 (*below*).—A 24-hour-record of meteor activity on June 11, 1949, obtained using the radio-echo technique. Each line represents a meteor and it is known that the rate of the echoes corresponds closely with the rate seen by a visual observer. The diagram illustrates the great activity during the summer daytime. The radiants of the active showers can be deduced from the range-time distribution.



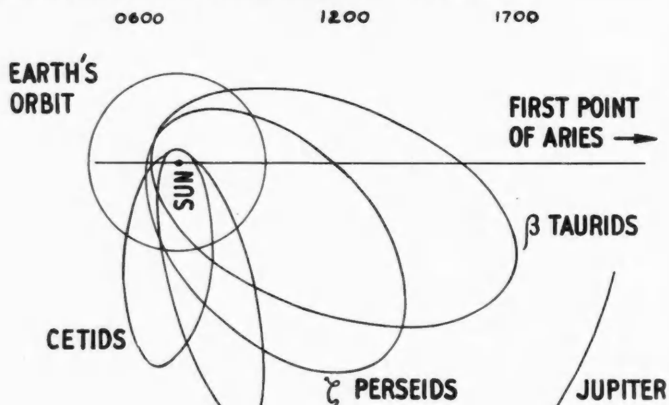


FIG. 3.—The orbits of four of the main summer daytime streams of meteors projected on to the plane of the ecliptic. The orbit of the β-Taurid stream lies nearly in the plane of the ecliptic and is coincident with that of Encke's comet

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Radio Astronomy

A. C. B. LOVELL, O.B.E. Ph.D., F.Inst.P., F.R.A.S.

DURING the last few years the application of radio techniques to problems in astronomy has yielded results of great interest. In some cases—such as in the study of meteors—the new techniques have revolutionised subiects which have been investigated visually for many years; in others entirely new avenues of research have been opened, and here most puzzling and surprising results have already been obtained.

The origins of Radio Astronomy go back many years. In his early experiments on the ionosphere, Sir Edward Appleton found the short-lived radio echoes which we now know to be caused by meteors, and at about the same time in 1932, Jansky, working in America, made his famous discovery that radio waves from outer space reach the earth. The scientific literature of the ensuing years up to 1939 contains a certain amount of discussion about the transient radio echoes—mainly concerning their origin—but no effective application of the radio technique was made in meteor astronomy. Jansky's remarkable discovery appears to have been almost entirely neglected by professional scientists, the only effective follow-up being made by Reber, an amateur, who conceived and built the most advanced type of apparatus in the garden of his home in Illinois. But during the war rapid advances in radio technique were made, and in 1945 there existed physicists who had become acquainted with the potentialities of these new developments. Radio Astronomy then began its evolution into a virile science which, in a few years, produced results of fundamental cosmological importance.

The Astronomy of Meteors

The study of shooting stars, or meteors, which are often seen as bright transitory streaks of light in the clear night sky, has been the Cinderella of astronomy. Systematic investigation by visual or photographic techniques has not been possible because of the hindrances caused by cloud and moonlight, whilst no daytime observations have been possible. Nevertheless, during the last hundred years a good deal has been discovered about the general phenomena. Some 8000 million meteors enter the earth's atmosphere every 24 hours and all except a few extra large ones burn away in the high atmosphere, about 80–120 kilometres above the surface of the earth. Most of these meteors are too faint to see with the unaided eye, and apart from the meteor showers a single visual observer only sees from 2 to 10 per hour, depending on the season and time of night. At certain times of the year this hourly rate increases markedly for a few nights and a meteor shower can be observed; on these occasions the earth moves through a concentration of debris in space as illustrated in Fig. 1. The meteors enter the atmosphere in nearly parallel paths, but due to the effects of perspective they appear to radiate from a small point, or area, in space. By convention the meteor shower is named after the constellation or star near which this radiant point lies. From the fact that several of these showers recur regularly at the same time every year, it was concluded that the debris must lie in an orbit with the sun at the focus. There are about a dozen well-known night-time showers, such as the Perseids, which last for two weeks in August and give a maximum hourly rate of about 50, and the Geminids lasting for about a week in December with a similar hourly rate. The orbital velocity of the earth is 30 kilometres per second, and hence the debris giving rise to a shower such as the Perseids must extend for some 50 million miles in space.

What is the origin of this enormous amount of debris? Is it localised in the solar system, or does it come from interstellar space? Is it the debris of comets? Is it some of the primeval dust left over from the formation of the solar system? Or is it the result of planetary disintegrations? We shall now see how the radio techniques are enabling great progress to be made in the solution of these problems.

Radio Techniques for the Study of Meteors

When a meteor enters the earth's atmosphere it disintegrates through collisions with the atoms and molecules of the air. The initial kinetic energy of the meteor is spent in heat, light and ionisation in the ratio of about $10^4:10^2:1$, and the resultant visible trail and column of ionised matter extends for about 10 kilometres in length before the disintegration is complete. A radio wave incident on this ionised column causes the electrons to oscillate and the small amount of energy which is thus re-radiated can be detected on a sensitive radio equipment. The commonest form of equipment is basically similar to a conventional radar equipment in which the transmitter radiates several hundred pulses per second, each with a duration of a few microseconds. (A microsecond is a millionth of a second.) The radio waves scattered by the ionised column of the meteor, are picked up by the radio receiver, and can be made visible as short-lived echoes on a cathode ray tube display. As will be seen later, more complicated receiving techniques have been devised for special purposes.

It was known from the early observations of Appleton in Great Britain, and of Skellett in America, that some of the transient echoes observed with such equipments were associated with meteor ionisation, but on the wavelengths then used (longer than 10 metres) there were very large numbers of these echoes and the attempts to identify them with the general features of meteoric activity were unsuccessful. In 1945, J. S. Hey and his associates of the Army Operational Research Group, were using the anti-aircraft radar sets, known as 'GL', on wavelengths of 4 metres to detect the V2 rockets. They found some echoes which were at first thought to be from rockets, but which were later shown to be associated with meteors. In a very short time Hey had shown that on these frequencies the reflection of the radio waves from a meteor trail were specular so that an echo was obtained only when the meteor passed through the aerial beam in certain directions. He used this feature to devise a method of determining the radiant of an active shower. Subsequent development of these techniques followed rapidly—mainly by Hey, by workers at the University of Manchester Experimental Station at Jodrell

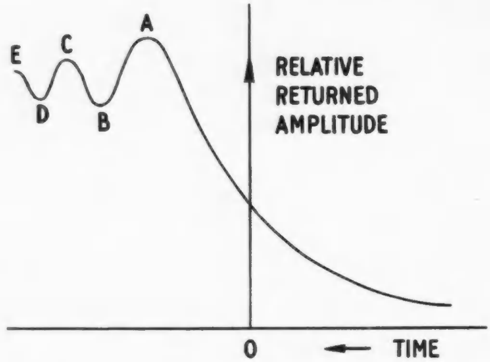


FIG. 4.—Variation in amplitude of radio echo due to the scattering of radio waves from a meteor trail, as it forms across the foot of the perpendicular from the observer to the trail. The Fresnel zone maxima and minima should be compared with those in the actual photograph shown in Fig. 5.

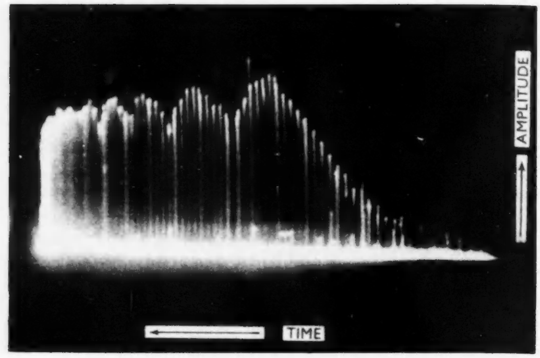


FIG. 5.—The diffraction of 37 Mc/s radio waves from a meteor trail during its formation. The maxima and minima of amplitude correspond to the Fresnal zones A B C D E . . . in Fig. 4. The time interval between successive pulses is 1·66 milliseconds. The range of the meteor was 275 km. and its velocity measured from the zone spacings 51·7 ± 2·3 km./sec.

Bank in Cheshire, and later by groups in Ottawa and Stanford. We shall now describe some of the more important features of the contemporary results.

The Great Daytime Meteor Showers

The radio techniques possess the unique advantage of enabling meteor observations to be made in daylight. During 1945 and 1946 there seemed to be an unusually high rate of meteoric activity during the summer daytime, but the significance of these observations was not fully appreciated until 1947. By that time Clegg had devised an accurate method of determining radiants, using a single directional aerial, and the method was in use at Jodrell Bank for a survey of the meteoric activity. The apparatus was adjusted so that the echo rate corresponded closely with the visual rate for a single observer, that is from 2 to 10 per hour, rising to 50 or so during showers like the Perseids and Geminids. During the autumn and winter of 1946 the echo rates corresponded closely with the visible events. But in early May 1947 the η-Aquarid shower, already known to visual observers, was found to be accompanied by other showers whose radiants were above the horizon only during daylight hours.

The occurrence of unknown showers during the daytime was not unexpected, but what was remarkable was that the activity increased without intermission as the summer advanced, until by mid-June the daytime sky was evidently a blaze of meteoric activity. Thereafter the activity diminished gradually and returned to normal in August. In subsequent years these events were studied in more detail, and recently successful velocity measurements has been made on several of these daytime showers. The striking nature of this daytime activity is illustrated in Fig. 2 which shows a 24-hour record in mid-June. The hours of darkness, during which meteors are visible, are indicated; but the existence of the immense activity during the day has hitherto been unknown. This activity is now known to be comprised of a series of intense meteor showers, of which at least four are recurrent. The dominant stream of the sequence is the Arietid shower (see Fig. 3), active from the end of May to the end of June with an hourly rate greater than that of the night-time Geminids. The debris in this orbit must extend for about 100 million miles in space, and be about twice as packed as the debris which gives the Perseid and Geminid showers.

The orbits of these streams have now been delineated through the combined work of Davies, Aspinall, Hawkins, Greenhow and Miss Almond at Jodrell Bank, and the surprising feature is that they are all of very short period, lying inside the orbit of Jupiter (see Fig. 3). With one exception the orbits are of too short a period to be associated with comets and are too eccentric to be associated with any known bodies in the solar system, apart from one or two unusual minor planets. The exception is the β-Taurid shower active at midsummer, whose orbit coincides with the orbit of a comet of unusually short period known as Encke's comet. There also exists a well-known autumn night-time shower with its radiant in Taurus. In 1942 Whipple had concluded that this was associated with Encke's comet, and he made the remarkable prediction that it would give rise to meteors "perhaps observable as fireballs in late June or early July".* This prediction was fulfilled when the daytime β-Taurid shower was discovered 5 years later by the radio-echo techniques.

There is convincing evidence that the debris of many of the night-time showers is associated with comets. For example, on October 10, 1946, the earth crossed the orbit of the Giacobini-Zinner Comet only 15 days behind the comet, and for a short period the radio-echo rate increased by 5000 times. Apart from the β-Taurid shower, these great daytime showers appear to move in orbits which are not associated with comets. Perhaps they are the debris of

* The orbit is almost co-planar with the earth's orbit and hence the earth crosses through it before and after perihelion. In the former case the meteors will be observed as a night-time shower in the autumn, but the latter case they will be incident on the sunlit side of the earth in the summer.

some of the minor planets. This is one of the many intriguing problems which lie ahead in this meteor work.

The Significance of Meteor Velocities

Meteors enter the earth's atmosphere at great speeds—in the region of 100,000 miles per hour. The precise measurement of these velocities is of fundamental importance to meteor astronomy; without it the orbits of the shower meteors cannot be computed. The great difficulty of measuring these high velocities by visual techniques has severely hampered the progress of the subject, and has led to a prolonged and fierce dispute between rival schools, one of which holds that all meteors move in closed orbits and are confined to the solar system, and the other that a large percentage of the sporadic meteors move in hyperbolic orbits and are visitors from interstellar space. There is a critical velocity, above which any meteor must be moving in a hyperbolic orbit, but until the advent of the radio techniques it had not been possible to decide whether a proportion of the meteors exceeded this limit.

There are now several radio techniques for the measurement of these high velocities. The one most extensively used observes the Fresnel diffraction pattern as the column of ionisation forms across the aerial beam. As the meteor approaches the right-angled reflection point the intensity of the scattered wave will increase, but after passing O (Fig. 4) the scattered intensity will pass through maxima and minima. If the time between these successive maxima and minima is determined, the speed with which the meteor is moving can be calculated. The phenomenon is strictly analogous to the case of the diffraction of light at a straight edge. In the method developed by Davies and Ellyett at Jodrell Bank the meteor echo initiates a sequence of events such that a photograph is obtained with the successive transmitter pulses spaced by about a millimetre on the film. The interval between these pulses is known with precision, and hence the time between the maxima and minima can be measured. An example is shown in Fig. 5. A similar method, but using continuous wave instead of pulse, is being used by McKinley and Millman in Ottawa.

The pulse technique has been used to measure the velocities of the daytime shower meteors with the results described in the previous section, and both techniques have been applied to the problem of the interstellar meteors. The results of a long series of experiments, made both in Ottawa and at Jodrell Bank, prove that no hyperbolic meteor velocities exist in the range of visible meteor magnitudes. At present the radio measurements strengthen the case of those who believe that all meteors—sporadic or in showers—are members of the solar system.

Radio Waves from outer Space

So far we have described a branch of Radio Astronomy in which radio waves are transmitted, and the signal received on the earth is reflected from an electron column in the high atmosphere. Another subject in Radio Astronomy and one which is of more far-reaching cosmological importance, concerns the reception of radio waves which are being generated by some processes in outer space. The discovery that radio waves were reaching the earth from some extra-terrestrial source was made by Jansky in 1932. He was studying atmospherics from thunderstorms and noticed that even in the absence of thunderstorms a high noise level existed, which showed a diurnal variation in intensity. His crucial observation was that, for a given aerial direction, these signals rose to a maximum every 23 hours 56 minutes—the period of the earth's rotation relative to the stars—and this indicated that their source was fixed with respect to the stars. Both Jansky, and Reber who soon commenced independent experiments, found that these incoming radio waves were most intense from the direction of the Milky Way, but when their aerials were directed at the bright visual stars no increase in signal strength could be observed.

In 1945 in England, Hey and his colleagues made a careful survey using ex-army radio receivers on a wavelength of 4 metres. They confirmed the general conclusion of Reber and Jansky that the intensity of the radio emissions varied more or less in proportion to the stellar density in the galaxy—that is they were most intense from the direction of the centre of the galaxy and at a minimum from the poles; but they also failed to find any relation between the emissions and known types of stars. In view of these results it was generally believed at that time that these radio waves were being generated by some process in the interstellar gas of our galaxy, as originally suggested by Reber.

The Discovery of Radio Stars

Our existing knowledge of the universe has come from studies of the visible radiation and the near infra-red and ultra-violet radiation emitted by the stars. It is a strange evolutionary coincidence that our eyes are sensitive only

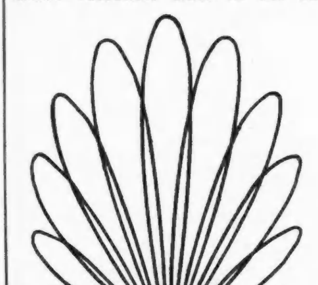
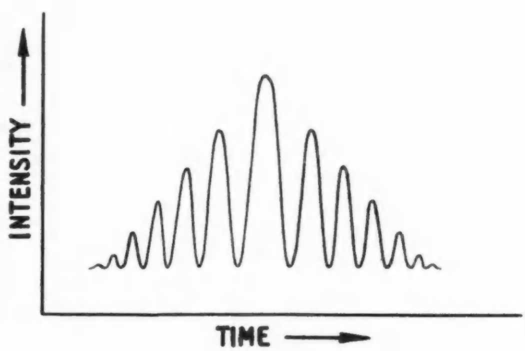
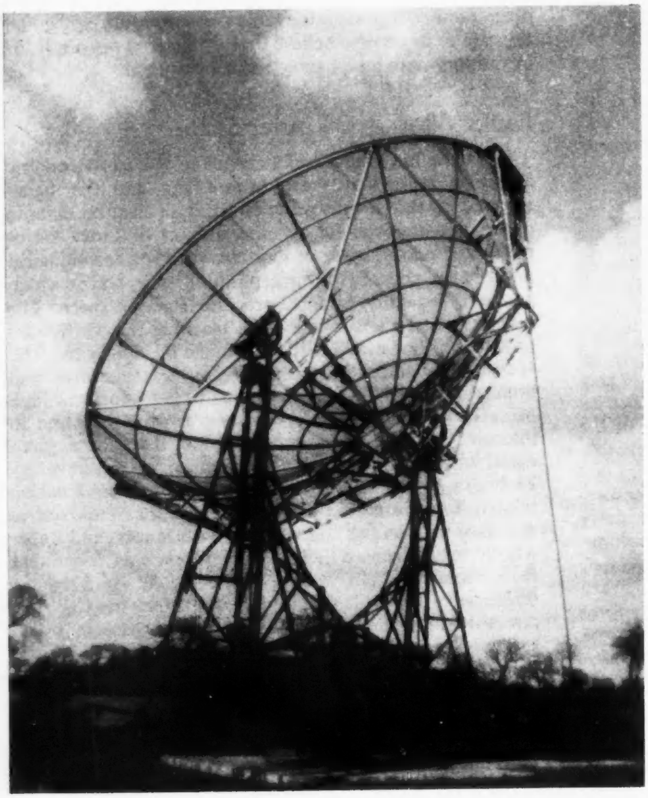


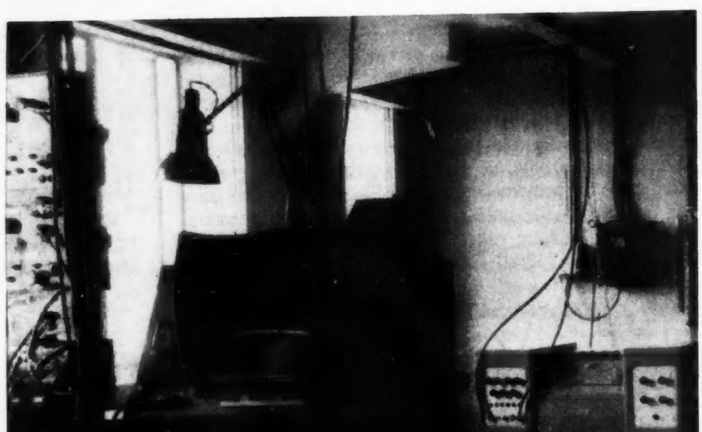
FIG. 6 (*left*).—Polar diagram of two aerials spaced by several wavelengths showing lobe system.

FIG. 7 (*right*).—Type of record obtained as a radio star sweeps through the interference pattern of Fig. 6. The celestial co-ordinates can be computed from the time of occurrence of the central maximum and the periodicity of the pattern.





A 30-ft. aperture steerable paraboloid used as a radio telescope in Radio Astronomy at the Jodrell Bank Experimental Station in Cheshire. The instrument can be used over a wide range of radio frequencies by changing the dipole aerials at the focus. Those shown worked on a frequency of 81 Mc./s. and the instrument then had a beam width of about ± 20 deg.



Some of the meteor recording equipment in use at the Jodrell Bank Experimental Station. The receiver and cathode ray tube display can be seen on the left. The automatic recording instrument for the measurement of meteor velocities is in the back centre of the photograph.

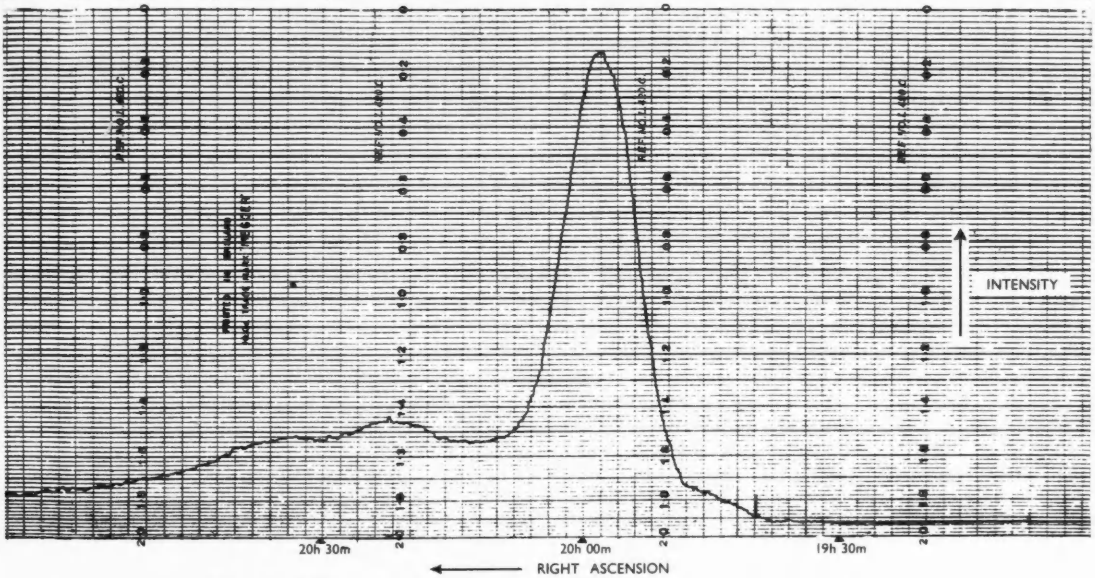


FIG. 8.—The radio star in Cygnus as recorded on a narrow pencil beam aerial system. The record was obtained on 160 Mc./s. using the 220-ft. aperture paraboloid where the beam width is $\pm$ 1 deg. The intensity received from the radio star is 5×10^{-23} watts/sq.m./c.p.s.

to that region of the spectrum which can penetrate the earth's atmosphere without complete absorption; for, outside that region, from about 10^{-3} to 10^{-5} centimetres, incoming radiation is totally absorbed by the atmosphere. There is another and more extensive 'window' through the atmosphere; this is in the radio wave region extending from a few millimetres to about 20 metres.* Jansky's discovery revealed the unexpected fact that we could also 'see' an outer universe through this radio 'window', but the profound significance of this was not appreciated until 1948 when a remarkable discovery was made almost simultaneously by Bolton and Stanley in Sydney, and by Ryle and Smith in Cambridge. They found that at least some of the radio emissions were coming from very localised regions in space. Two intense sources—in Cassiopeia and Cygnus respectively—and several minor ones were found immediately. The surprising feature of this discovery was that none of these sources coincided with any prominent stellar objects. In fact in the neighbourhood of the intense sources in Cassiopeia and Cygnus there are only very faint stars.

Although the radio methods have advantages over visual techniques of the ability to work through cloud and daylight, they have one fundamental disadvantage. The wavelengths are some 6 million times longer, and even with the greater aperture of the radio telescopes compared with the optical telescopes (say 200 ft. to 10 ft.) the powers of resolution are some 300,000 times worse. Bolton and Ryle and their colleagues overcame this difficulty to a certain extent by an ingenious adaptation of interference principles to the radio work. Ryle used two aerials, separated by a large number of wavelengths, connected to the common input of a receiver. This arrangement gives a resultant polar diagram with a lobe system as shown in Fig. 6. As the

* The cut-off at the short-wave end is caused by atmospheric absorption, and at the long-wave end by ionospheric absorption.

earth rotates this lobe system will be swept across the sky and if the angular dimension of the emitting source is large compared with the lobe separation, then the receiver input will be steady or slowly varying. But if the angular dimensions of the source are less than the lobe separation, then the receiver input will go through a series of maxima and minima as indicated in Fig. 7.

The dimensions of the source can be estimated from the ratio of maxima to minima, and if the position of the aerials is accurately known, the right ascension of the source can be obtained from the time of occurrence of the central maximum in the interference pattern, and the declination from the periodicity of the pattern. (Ryle's method is closely analogous to Michelson's stellar interferometer in which he arranged two mirrors, separated by several feet, to reflect the light of a star into the 100-inch Mt. Wilson telescope.)

Bolton's method also uses an interference technique, but in this case only one aerial is used, mounted on a 400-ft. cliff overlooking the sea. The lobe pattern is produced by the interference between the direct radiation and that reflected from the sea. (This system has its optical analogy in the Lloyd's mirror interferometer.)

With the maximum practicable baseline in the radio interferometers the angular dimension of the localised sources of radio emission could not be measured, and at present it is only known that their dimensions are less than 1 minute of arc. This may be compared with the angular dimensions of the brightest stars measured by Michelson which are about 0·03 seconds of arc.

What are the Radio Stars?

So far the interferometers in the southern and northern hemisphere have demonstrated the existence of about 100

such localised sources or radio stars. We now believe that this number is limited by the sensitivity and the resolving power of the radio equipment. A considerable amount of experimental and theoretical work is now showing that there must be vast numbers of these radio stars in our galaxy. In fact there are grounds for believing that there may be as many radio stars as visible stars (10^{11}) in the local galaxy. A being with 'radio eyes' could see the intense sources in Cassiopeia and Cygnus as bright stars standing out above the background, with about the same prominence as we see Sirius and Capella standing out above the background of diffuse visible light. With a radio telescope the being would see the radio light from the Milky Way resolve into more and more stars as he increased its aperture, in the same way as the visible Milky Way resolves into myriads of stars when viewed through the big optical telescopes.

The nature of these radio stars now presents one of the greatest contemporary problems in astrophysics. With three exceptions none of the known radio stars coincides with any particular types of stellar objects already catalogued. Bolton has found that three of his radio stars coincide with unusual objects in the galaxy, the most interesting being the coincidence of a source in Taurus with the Crab Nebula. The Crab is believed to be a vast mass of hot expanding gas resulting from a supernova which occurred in 1054 AD. But no such objects can be related to the bulk of radio stars, and indeed the two most intense of these lie in parts of the sky devoid of any bright stars.

One possible explanation is that the radio stars are included in the normal sequence as stars of low luminosity, but that they possess peculiar properties enabling them to be powerful emitters of radio waves. Another possibility is that the radio stars are 'young' stars which are not yet hot enough to be seen.

Again, the radiation may arise from electromagnetic processes in the neighbourhood of certain stars. The trouble with all such speculations is that no one has yet produced a perfectly satisfactory explanation for any of the processes; and it seems unlikely that the problem will be solved until the limits on the angular dimensions can be reduced. Although the ability to position the sources and measure their diameters to within a few minutes of arc is a most remarkable achievement, these limits are still 10,000 times greater than the limits of technique in the visible region. Thus, as far as is known at present, the radio stars may extend over areas of space which are vast compared with the space occupied by the visible stars.

Radio Emissions from the Extra-galactic Nebulae

Until recently there has been no real evidence as to whether our local galaxy is unique in its generation of these radio emissions. Although most workers had attempted to detect similar radio emissions from the nearer external galaxies no definite success was achieved until the summer and autumn of 1950, when, in a striking series of measurements made at Jodrell Bank in Cheshire, Hanbury Brown and Hazard succeeded in detecting and measuring the radio emission from the great nebula in Andromeda known as M.31. This, the nearest of the external spiral nebulae, is 750,000 light years distant, and the intensity of

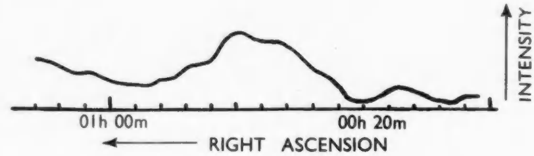


FIG. 9.—The radio emission from the Great Nebula in Andromeda (M.31). The intensity received is 4×10^{-25} watts/sq.m./c.p.s.

the emission received on the earth is only about 1/700th of that received from the intense radio star in Cassiopeia. Success was achieved by using the 220-ft aperture radio-telescope at Jodrell Bank; this operates on a wavelength of 1·9 metres where the beam width is ± 1 degree. The intensity of the signal from the nebula was 4×10^{-25} watts/sq. metre/cycle per second bandwidth. A sample record compared with that from one of the local radio stars is shown in Figs. 8 and 9.

From these measurements it is possible to deduce that the Andromeda nebula must generate radio emissions in a very similar manner to our own galaxy—in fact, the results are consistent with the view that the nebula contains some thousands of millions of radio stars of an absolute magnitude similar to those in our local galaxy. Since the local galaxy and the M.31 nebula are regarded as being typical star systems in the universe (of which some thousands of millions can be seen in the big telescopes), we are now faced with the prospect that the radio stars are as common in the universe as the visible stars.

In this article it has been possible to discuss only two typical subjects which are embraced in the new science of Radio Astronomy. No mention has been made of the radio emissions from the sun—now a vast subject in itself, of the utmost importance to the understanding of solar and stellar atmospheres, and an important avenue through which the nature of the galactic emissions may be eventually revealed. Much interesting detail has been omitted from the story of the galactic radio emissions—such as the twinkling of the radio stars, and the ability to study the great volumes of our galaxy which lie hidden behind the dust clouds. Reference has been made to only one or two topics in meteor astronomy, and no mention has been made of the physics of the phenomena—a complicated and difficult subject which is now yielding information about the processes of ionisation, the scattering of the radio waves and the meteorological conditions in the high stratosphere. Finally, a new instrument is available for the study of the aurora borealis, and, as many readers may see for themselves at the 1951 Exhibition, the study of the radio echoes from the moon provides a new method for exploring the conditions in the space between earth and moon and the nature of the lunar surface.

FURTHER READING

In the following recent surveys of various aspects of Radio Astronomy, references to the original work will be found:

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A. C. B. LOVELL, "Meteor Ionization in the Upper Atmosphere," *Science Progress*, 38, 22, 1950.

Man Against Locust

J. S. KENNEDY, Ph.D.

TALES of the flying swarms of adult locusts, which can bring darkness at noon, or of the marching armies of wingless immature locusts—and of the devastation left in their wake, have caught the imagination of us all. And we all know that the locust is no new enemy of man. It was the Desert Locust which formed the eighth plague of Ancient Egypt; in fact locust plagues are probably as old as agriculture. Our own century has witnessed a succession of them, and now, once again, crops are being threatened over the huge area from India in the east to the Atlantic coast of Africa in the west, from the Caspian Sea in the north to Tanganyika in the south.

Why, you may ask, hasn't more been done to stop these outbreaks? The answer is, a great deal has been done. Like any marauders, locusts are bad enough when you know they are coming, but they are far worse when you do not. Until a few years ago, people seldom did know, and that made for a rather fatalistic attitude toward locust invasions. If warnings can now be issued, that is only because over a period of years reports have been sent in to the Anti-Locust Research Centre in London from all over the world. There they have been painstakingly pieced together until a reasonably connected picture has emerged of what the locusts are likely to do, in the way of breeding and migration, in any region at any time. Not only that, but the technique of killing locusts when they do appear has made enormous strides. But this means we still have to fight the fully mobilised locust armies, and engage in an arduous, costly kind of war in which victory is never final.

Why have we not tamed this wild competitor for our food supplies, as we have others? The main aim of the Anti-Locust Centre and its director Dr. B. P. Uvarov has always been just that. But the first thing needed was a great deal more knowledge about locusts. There is not just one, but a number of different kinds of locust, each adapted to life in a particular climate and particular type of country. And the swarming locust is a mobile, elusive subject of study. The biggest mystery of all was what happened to the locusts when they were not swarming. After a run of plague years, not only the swarms but even the individual insects disappear completely, everywhere, only to reappear several years later.

The Two Phases

This mystery has been cleared up only in the last thirty years. A locust is simply a kind of grasshopper—a grasshopper which runs amok from time to time. Between plague periods, locusts live like other grasshoppers, as scattered, inconspicuously-coloured insects leading solitary and mostly very quiet lives. But unlike ordinary grasshoppers, when these are crowded together they change into a brightly coloured, gregarious and intensely restless form, so different from the solitary form that it was once taken for another insect altogether.

It was Dr. Uvarov who first made the discovery that the solitary and gregarious forms belong to the same species, and some biologists would not believe it at first; they even tried to prove experimentally that the two forms really were two distinct species which merely hybridised. But the men who had the practical problem to solve went on to prove their point conclusively: that the two so-called 'species' could be converted one into the other simply by keeping the insects apart, or by keeping them crowded together. Here at last was the key to the origin of plagues.

It was more than that. It was a discovery of first-class importance for biology generally, because the changes induced by crowding proved to be hereditary, showing up in the offspring of crowded parents even if the offspring themselves were not crowded. Biologists not directly concerned with locusts, but interested in heredity, could well have taken up this discovery in their own interests. Unfortunately, the prevailing theory of heredity says that hereditary changes are quite haphazard: that is, they bear no relation to the changes parents undergo in the course of their own lives. Locusts just do not fit that theory and were passed by.

Fortunately the economic motive behind the study of locusts was too strong for that theory, however well entrenched in academic circles, to stop the locust workers from going ahead on their own to exploit the discovery of 'change of phase', as the transformation from the solitary to the gregarious form and back again is called. And their work in the years between the wars has built up this general picture of how an outbreak starts. The first requirement is a period when conditions are particularly favourable for the solitary insects to live and breed, so that they multiply rapidly. For the Desert Locust, the crucial condition seems to be extra good rains, so that extra generations can be squeezed in before the country dries up again and breeding stops. But to produce gregarious swarms from the myriads of scattered insects then present, a *less* favourable period must follow the more favourable one. When that happens, the insects can find suitable living conditions only in restricted areas, and they get very crowded there. Frequent meetings of insect with insect set off a train of changes inside each insect, as a result of which their behaviour, colour and shape all change. They become *attracted* to each other, yet at the same time *hypersensitive* to each other's movements, so that their excitement grows until they cannot keep still. In a few generations they have ceased to be solitary grasshoppers, and have gathered into great swarms which sally forth on the restless, far-ranging flights which make them such unexpected and catastrophic pests.

The important thing is that this sequence of events can occur only in a few, relatively small places within the whole region inhabited by each kind of locust. The solitaries may often become very numerous elsewhere, but if there's little crowding no swarms are produced to emigrate and spread the damage. And since, generally speaking, the old-world locusts live mainly in regions that are under-developed agriculturally, the damage they do is not often serious as long as they remain solitaries and stay at home.

Thus the way to deal with the locust problem became

clear. It was to locate the special 'outbreak areas' and, as a first step, to destroy the swarms there before they got away. As a second step, to seek the best way to alter the conditions of vegetation and so on, so that swarms never form, thus finally solving the problem.

With these aims in view international organisations have recently been established in the outbreak areas of two of the African locusts. Success can already be claimed in suppressing outbreaks of these two: the Red Locust of East and South Africa and the one called the African Migratory Locust whose home is in West Africa. The third main African locust is the Desert Locust which has now broken out again, for it is a much more difficult problem. Its outbreak areas are in semi-desert regions, more numerous and less constant in locality from year to year, and they form an interconnected series spreading across many more frontiers not only in Africa but way across to India.

Turning back now to the question we started with, as to why progress had not been quicker, you will see that this is much more than a scientific or technical matter. I have touched on the scientific and technical obstacles, including some inside the heads of scientists. But the main reasons for the slowness first in getting the necessary information, and then in applying it, have not been technical.

The fact is that until rather recently the tendency of governments has been to pour out money to deal with a locust plague once it was upon them, but to lose interest when it eventually subsided from natural causes. Every country was inclined to blame its neighbours for sending the locusts: a convenient excuse because there was this much truth in it: that locusts are in any case migratory insects and inevitably do move to and fro across frontiers a great deal. So everyone was caught again the next time, and the all-important job of finding out where the swarms really originated went ahead only slowly.

International Pest Control

Once the necessary knowledge was available, so that a plan for plague prevention could be worked out, similar obstacles still stood in the way. The plan was a long-term one: something which did not go very well with hand-to-mouth economics. And since the locust knows no frontiers, the plan called for co-operation by many different countries, above all against the Desert Locust. So although the principles of such a plan were there many years before the last war, international agreement to implement it was obtained only in 1938. Now at last the plan is being implemented

The Mormon Cricket, a wingless grasshopper, now an expensive pest in the United States. (*U.S. Dept. of Agriculture photo.*)

—at any rate for the two locusts I have mentioned. It may well turn out that the final *prevention* of swarming by some locusts will be economically possible only as a by-product of plans for general agricultural development, which, after all, would be the happiest solution.

The Grasshopper Problem

If the problem of grasshoppers in their locust form is in sight of solution, that is no small achievement, but it does not necessarily mean that our grasshopper troubles will soon be over. The possibility of preventing locust outbreaks, by upsetting their home-life, exists just because the locust is a raider from the wild, a prehistoric kind of pest. But most of our modern pests are not of that kind. They do not invade our crops from the outside, but develop in them. That is to say, man not only feeds but directly breeds them, when he goes out blindly for quick returns from the land. If, as a result of large-scale single-crop farming, conditions are kept so favourable for grasshoppers in general that the potential locusts among them never turn into the swarming form, then they, together with the ordinary grasshoppers, become a perennial plague, less spectacular but actually worse than the locusts before. Swarming locusts did exist, for example, in the United States in the early pioneering days. That problem was 'solved', unwittingly, by the spread of settled agriculture across the continent, but its place was taken by a grasshopper problem which cost the United States £52 million pounds in 1925–34 and £100 million pounds between 1936–46.

You will see from this that the grasshopper problem is by its very nature more awkward than the locust problem. But even here the difficulty is not primarily technical: the difficulty is to get people to take the long view. What is needed is a scientific study of farming practices in relation to grasshopper biology, a study aimed at making life in man's fields less easy for the grasshoppers, by some simple and cheap modification of those practices. It can be done; some promising suggestions can be offered straight away, although they need to be worked out. But as things are in America now, it does not seem possible to raise the necessary money for such long-range research. Indeed it seems futile to contemplate a policy of plague prevention which requires planning and execution on a continental scale. So what we have instead is ever-increasing sales of new and more deadly poisons to kill the insects which man himself is at the same time blindly encouraging. Since insecticides do not prevent plagues, the killing operations have to be repeated endlessly. Even the biologists are pressed into this mad merry-go-round, for they are kept too busy testing the new chemicals to be left with much time to investigate the causes of plagues.

That is how we stand in the war against the grasshopper tribe. We have beaten some locusts, but by accident rather than design. There is hope of beating some others deliberately, and soon. But to beat the remaining locusts, and the more insidiously dangerous grasshoppers proper, we shall have to do a lot more. And we shall have to take to heart the lesson of experience so far: that *man gets the pests he deserves*. By that I mean that the technical difficulties, however great, are always secondary to the difficulties created by men.

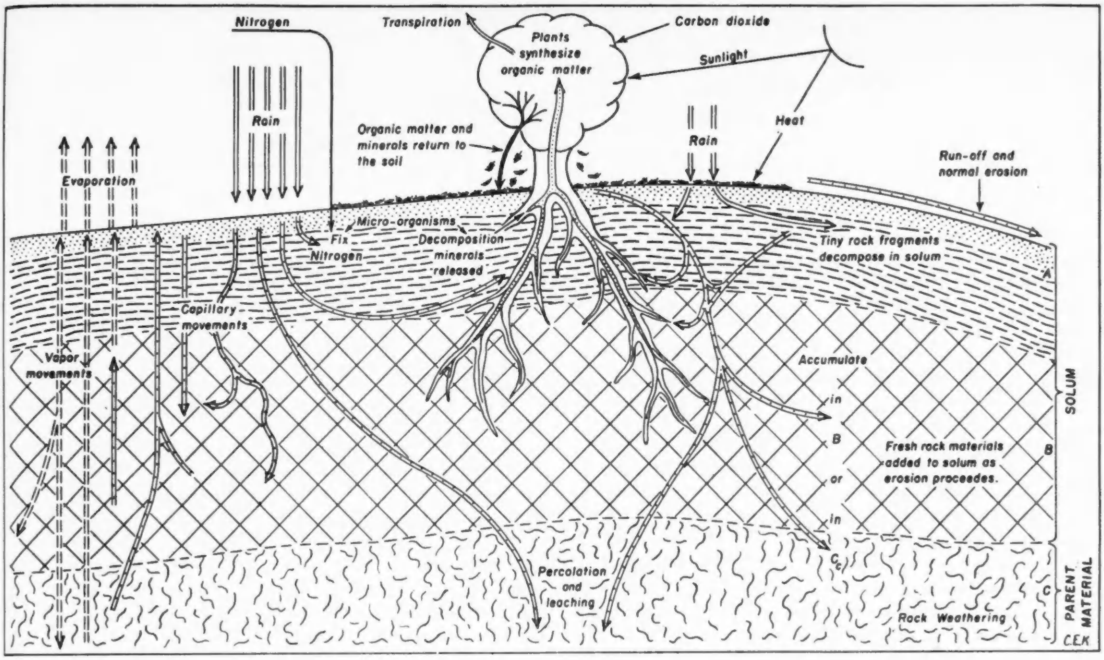

FIG. 1.—The diagram shows the interlocking cycles which lead to the conversion of rock into soil and make for the maintenance of a cover of vegetation on the ground and the maintenance of the soil.

The Living Soil

W. T. H. WILLIAMSON, Ph.D., F.R.I.C., F.R.S.E.*

MOST people know that soils are somehow or other derived from rocks. But a mass of weathered rock does not make a soil and never will, without the intervention of living processes, and it has come to be realised in recent years that a soil is a natural phenomenon to be studied in relation to its environment, just as a plant or an animal would be. Soil science is now taking its place among the other natural sciences. It is no longer merely a branch of applied chemistry or physics, although naturally the techniques of these fundamental sciences are all important in soil investigations. It is concerned with the study of soils as biological entities and not just as mixtures of mineral and organic matter. A sample of soil as examined by the chemist is such a mixture, but it bears the same sort of relationship to the real soil as ground-up leaves do to the growing plant from which they came.

Each kind of soil—and there are thousands of different kinds—has its own individuality. The distinctive feature of this individuality is the 'soil profile', which is conveniently studied when a soil is laid bare as, for example, in a cutting or a deep pit. It is seen to consist of a series of layers, which differ from one another in colour, texture, structure and other particulars. Each layer is called a 'horizon', and the succession of horizons down to the weathered rock forms the complete soil profile. (See Figs. 2–3.) Naturally the profile is best studied in a soil which has not been disturbed by cultivation; a virgin soil shows horizons near the surface which the processes of cultivation obliterate by mixing.

In order to study the soil as a natural body, the soil scientist, therefore, cuts a section, as the zoologist dissects an animal or the botanist a plant; for the scalpel or microtome, however, the soil scientist substitutes the pick and spade. From a study of his dissection he can identify the type of soil and can learn something of its history and its possibilities for crop or timber production. His field observations are necessarily supplemented by a laboratory examination—chemical, physical and biological—of the material making up each of the horizons. Profiles will show differing degrees of development and, with long-sustained altered conditions, they may even change from one type to another. But, at any given stage of maturity, each type of soil will exhibit a characteristic profile, identifiable in whatever part of the world it is found.

How have all these different soils arisen? Several factors have been involved:

(i) *The parent material*—the rock or rocks from which the soil has been formed. This is to a soil what the basic hereditary constitution is to a living organism. The kind of soil which eventually develops depends also on the environ-

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mental factors. When these vary, the resulting soils will also differ from one another, and so the same parent material can give rise to more than one type of soil.

(ii) *Climate*.—This determines the amount of washing through or *leaching* by rain water to which the soil is exposed, and it also affects the temperature at which this takes place. Variations in climate thus give rise to different kinds of soils.

(iii) *Vegetation* or other living matter.—This factor is influenced by the climate. It exerts its own effect on the soil-forming processes; what is left in the soil after the organic matter decays varies with the nature of the organic matter and with the climate.

(iv) *Topography*.—Two soils, formed from the same parent material, will differ if one of them develops in, say, a hollow where drainage is impeded and the other is produced on a freely drained site; they will be entirely different in appearance and characteristics. Similarly a soil that forms on a slope with a southern aspect may differ from one with a northern aspect.

(v) *Time*.—Soils are born, grow to maturity and may be destroyed. The kind of soil found at any given time will therefore depend on its age. Soils which have been destroyed may be reborn and again grow to maturity. The soils we know today have not necessarily been there for all time; other kinds may have preceded them and disappeared, to be succeeded by new soils which have developed into those we see today.

(vi) *Man*.—Man's use of soils has altered them; sometimes he has produced better ones than he found, often he has spoilt them and sometimes he has destroyed them altogether.

The Birth of a Soil

When we see lichens and mosses growing on bare rock, we are witnessing the birth of a soil. If we remove them, we see that pieces of the rock are flaking off beneath, and in the processes of breaking down the rock into smaller pieces the plants are helping. It may be that sooner or later enough loose material is formed for tree seeds to lodge in and germinate. As the trees grow, their roots find their way into cracks in the rock and widen them, thus accelerating the disintegration. In time a mature soil will appear.

More usually, however, a soil is formed on rock material which has already been reduced to relatively fine particles by weathering. Here again, with the advent of plant life, a soil is born. While the soil is growing the rains come and go and other factors are brought in to influence the development of the soil. Let us take the case of a temperate humid climate where the natural vegetation is coniferous forest. The rainfall exceeds the evaporation, so there will be considerable leaching. Any soluble salts and calcium carbonate in the surface layers of the weathered rock are dissolved and carried away by the percolating water. Similarly, the greater part of bases like sodium, potassium, magnesium and calcium, in combination with the surface of the clay or other minerals, are removed. The bases are leached out approximately in that order. This leaves the surface layers with an acid reaction. Moreover, the vegetable matter falling from the trees accentuates that trend; as it decays, it leaves near the surface a layer of raw humus and the decay processes release organic acids. These increase the solvent action and remove iron and aluminium compounds from the surface mineral layer. The iron and aluminium, however, are not entirely carried away, but are deposited lower down, as is also some of the organic matter itself. All these reactions produce the series of layers seen in the profile. (See Fig. 2.) The removal of the iron oxide, which normally gives sand grains their rusty-brown colour, leaves them with a bleached appearance. This results in a horizon of very loose structure below the raw humus; this horizon varies in colour from ashen grey to white. The deposition of the organic matter and the iron below this produces a dark layer succeeded by a brown one. Such soils are called *podzols*—the term derives from the Russian word *zola* meaning *ash* and *pod* meaning *underneath*.

It is obvious that, where the rainfall does not exceed the evaporation, the effect of leaching is not so intense and therefore an entirely different kind of soil is formed. Thus, in the case of the black steppe soils, the natural vegetation is grass, a type which does not leave an acid residue. The profile of these soils shows a deep black horizon (or horizons) composed of mineral matter which contains much humus, followed by lighter coloured horizons containing concretions or other deposits of calcium carbonate. Here, the leaching has gone only as far as to remove some of the calcium carbonate from the upper horizons, depositing it lower down; the surface soil remains rich in bases. These soils, known as *chernozems* (Russian for *black lands*), are among the most fertile in the world. (See Fig. 3.)

The fundamental principles of the modern study of the soil as a living body and the significance of the soil profile were first enunciated by the Russian scientist, Dokuchaev, in 1878, and developed by his pupils, notably K. D. Glinka. In a vast country like Russia there are climatic belts corresponding almost exactly with the various well-defined zones of vegetation. The Russian scientists observed that each of these regions had its own typical soil group with a characteristic profile. During this period, Hilgard in the United States of America had come to somewhat similar conclusions regarding the relationship of soils, vegetation and climate. Owing to language difficulties, however, the work of the Russian school did not become known in Western Europe and America until 1914, when there appeared a German translation of Glinka's book, *The Great Soil Groups of the World*. The dissemination of the ideas in this book had an enormously stimulating effect particularly in soil survey work, and many of the Russian words for soil groups came into general use.

While there is a tendency in large continental areas towards zonal soil groups, not all the soils in each zone will belong to that particular group. Where some factor other than that of climate and vegetation is dominant a different soil will result. Thus, in the podzolic zone, parent material of soft limestone generally produces not a podzol but something entirely different; this is very obvious in the chalk-lands of England, where the highly basic nature of the parent material counteracts the effect of the leaching. Then again, where the water-table is high, a soil known as a *glei** is developed. (See Fig. 4.) The blue-grey colour of the lower horizon under a fairly permanent water-table is due to the reduction of ferric oxide (rusty-brown in colour)

* Russian for *grey clay*—pronounced to rhyme with *clay*.

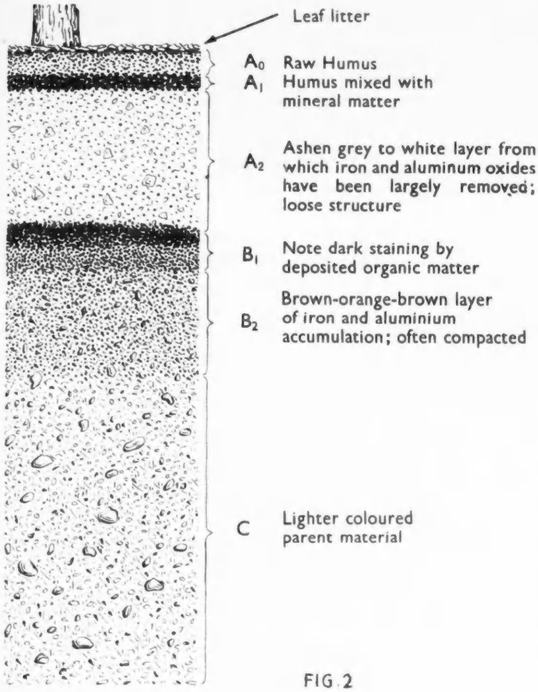


FIG. 2

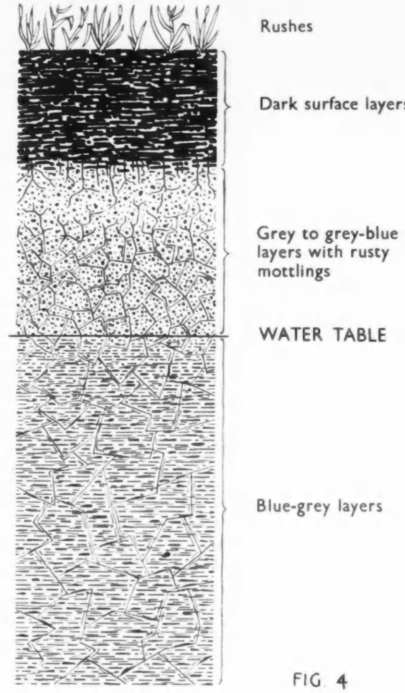


FIG. 4

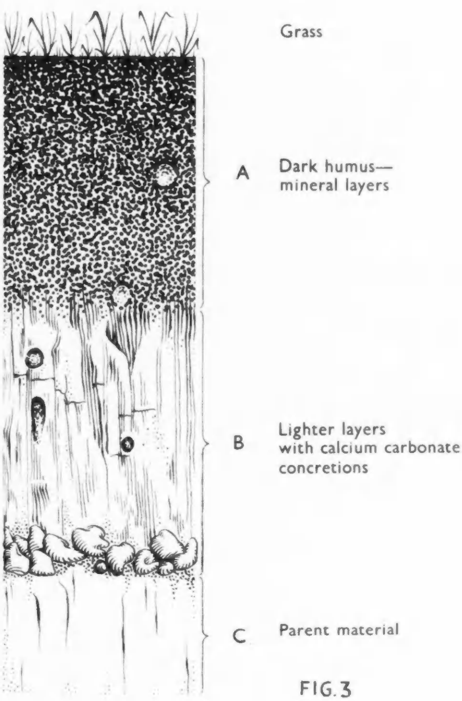


FIG. 3

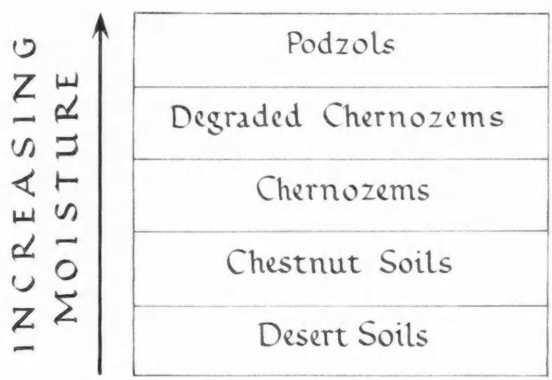


FIG. 5

to the ferrous state (blue). Above this layer, where the water-table fluctuates, there often appear spots or patches of rusty colour due to the partial re-oxidation of the iron compounds.

In a short article it is possible to give no more than a general idea of the appearance of a few of the most important soil profiles. Various modifications are found in practice; in Great Britain, for instance, the typical podzol such as I have described is the exception rather than the rule, and the great variations in this class of soil reflects the complicated geology of the country.

From the practical point of view, a soil is a medium for the growth of plants. The plant requires from the soil:

(i) a firm root-hold,
(ii) a supply of water,
(iii) a supply of air,
(iv) a supply of nutrients, which it can use to build up the structure of its own body and to synthesise its own food materials,
(v) absence of injurious substances.

The plant has other requirements, but these are the principal ones connected with the soil. For its supply of carbon, which forms such a large and important part of its structure and food, it is dependent on the carbon dioxide of the atmosphere, which by the process of photosynthesis is elaborated into complex organic compounds, such as starch. Sunlight is, therefore, a prime factor in plant growth. Another essential is a suitable temperature.

How complicated then is the problem of soil fertility! Should one of the necessary factors be absent, no matter how great the supply of the others, the crop will fail. Moreover, the factors are often interdependent. An excess of water in the soil means a deficiency in the air supply. More sunlight makes possible a greater utilisation of plant nutrients, given a sufficient water supply. Farmers may well grumble about the weather: in one year they get too much sunlight and too little water and in another year the reverse and they can do nothing about it. The farmer can deal with deficiencies of plant nutrients by suitable manuring, but soil fertility is not merely a question of the supply of these substances. In fact, some of our most highly prized soils are, in their natural state, low in nutrient content. They owe their value to their physical properties, being sufficiently retentive of moisture for good crop growth while remaining well-aerated. Such soils repay skilful cultivation and generous manuring. Generations of such treatment have brought their nutrient supply up to its present high level.

The factor of nutrient supply is in itself a complicated one: the nutrients consists of several elements, some of which are required in relatively large quantities and some only in minute traces. Yet if one of these elements is missing, plant growth is impossible. During the war, when we ploughed up our old pastures, we heard much about "cashing in on our stored-up fertility". Yet some of these fields, when sown to wheat or other crops, were complete failures. Some factor was missing. There was plenty of nitrogen and organic matter; the physical structure, when properly ploughed, was good, but neglect to maintain the supply of phosphorus or calcium, or both, had reduced the fertility to nil. In such cases, a dressing of a phosphatic fertiliser or of lime applied to the field meant the difference between no crop at all and a good one. Occasionally, the cause of failure in an otherwise fertile field was bad ploughing which did not consolidate the soil sufficiently. There were also cases of failure of oats due to deficiency of the trace element manganese, and failure of barley due to potassium deficiency. It is obvious that all these failures could have been prevented by suitable treatment and, in fact, after the first year of the war, they were largely (and ultimately entirely), prevented through the intensification and extension of the work of soil scientists in the advisory service of the Ministry of Agriculture, when it became possible to make tests for deficiencies in the soil of all fields being ploughed up. In cases of deficiency, a special allocation of the appropriate fertiliser was made to the farmer concerned over and above his usual ration.

The essence of good farming is keeping the soil in a satisfactory physical condition and maintaining the organic matter and plant nutrient supplies at the optimum level. Everything sold off the farm carries with it something removed from the soil. A moderate crop of wheat, for instance, removes from each acre of land almost as much phosphorus as is contained in a sack of superphosphate. A thousand gallons of milk carry away the same quantity of phosphorus together with a similar quality of lime. In good farming all these losses must be replaced.

In uncultivated soils such losses do not occur, all the materials of which the plants are composed being returned to the soil, where they undergo decay. This decomposition is brought about almost entirely through the agencies of living organisms. The first of these is the earthworm, which carries the plant residues down into the soil body, breaks them up into small pieces and leaves them in a suitable condition for attack by the micro-organisms of the soil, chiefly bacteria and fungi. In tropical soils similar operations are carried out by termites. In the more acid podzols there are no earthworms and it will be remembered that, in these soils, the plant residues form a layer of raw humus on the surface, which is not incorporated in the soil mass in the same manner. In such cases, the decomposition of the plant residues is mainly the work of fungi. The action of the bacteria and fungi on the material prepared by the earthworms results in the complete oxidation of part of the carbonaceous matter to carbon dioxide and water. The remainder is partially decomposed. The mineral matter is released and some of the complex nitrogenous compounds, such as proteins, are broken up into simple substances like ammonium salts. The residue is the dark-coloured substance which we call 'humus' and which is quite unlike the original plant material. In turn humus itself undergoes slow but continual decomposition. The mineral matter and some of the ammonium compounds are utilised directly by a fresh generation of plants. The rest of the ammonium compounds are acted on by special kinds of bacteria and are changed into nitrates, which again are taken up by the plants. There is thus a series of cycles involving the soil and the plant. (See Fig. 1.) A soil is never static, but always in a state of dynamic change. Even the parent material is continually weathering and adding fresh mineral matter to the soil profile as the surface gets worn off by natural erosion.

Natural erosion is very different from the cataclysmic erosion caused by man's mismanagement. Such catastrophies result from maladjustment of man to the limitations of the kind of soil on which he attempts to raise his

food supply or to his destruction of the natural vegetation —forests for instance—without providing a suitable alternative vegetative cover. Some parts of the world are more unfortunate than others in that they are subjected to periodic violent rain or wind storms, which greatly increase the dangers of erosion. In Great Britain such disturbances are infrequent. Nevertheless, our systems of agriculture are, for the most part, of such a nature as to combat the possibilities of such erosion as might occur. Particularly is this the case where ley-farming is practised, since this ensures that the land is periodically under grass.

A large number of our soils are of the podzolic type, naturally acid and with a tendency to what is called the 'single-grained' structure, which makes the soil behave like a loose sand and is therefore not conducive to good aeration. It is a constant struggle to keep such soils in productive capacity. They must be limed to counteract acidity and to replace losses by leaching; the original low level of plant nutrient status must be raised and maintained at a high level; the single-grained must be altered to the 'crumb' structure, in which the individual particles are aggregated into small sponge-like masses, permitting free access of air and free drainage. This is the type of structure which is the most suitable for crop growth and which renders the soil less prone to erosion. This condition is best attained by putting the soil periodically under a grass crop for a number of years.

When men move from one kind of soil to another, conflicts arise between old traditions and the demands of the new soil. Many adjustments are necessary for successful settlement in the strange environment. Without these adjustments mistakes will be made and, as already shown, even disasters may occur. When Englishmen first settled in the North East of what is now the U.S.A., they found there soils of the same types as those to which they were accustomed. Little adjustment was, therefore, necessary for them and the systems of agriculture they knew could suitably be practised in their new environment. English usages and customs were easily adapted to the new circumstances and the resulting social framework was little changed from that of the old country. Accordingly, English Common Law,* with little modification, was adequate for the administration of justice in a community made up principally of farms which were largely self-supporting. In later years, however, the trek to the West began and people settled on the soils of the grasslands there—first on the Prairie soils, then on the chernozems and finally on the chestnut soils still farther west—types of soil new and strange. After a period of cattle-raising the soils were ploughed up and given over to continuous grain-growing. With this mono-culture the farms were no longer self-supporting. They were necessarily larger and more dependent on world economic conditions. Under these vastly altered circumstances the provisions of English Common Law were no longer sufficient for the effective administration of justice and there followed the period of the lawless days of the 'Wild West'. The soil itself suffered. The natural good crumb-structure of the grassland soils was destroyed. This made them especially liable to wind erosion and, in extreme cases, the soils were completely blown away. The adjustment of man to soil in these areas is even yet not fully complete. The U.S.A., however, is making valiant attempts to deal with its difficult soil problems. No country has done more in developing effective measures for soil conservation.

Early in this century the Americans started a soil survey and by the time of the first World War the soils in many parts of the country had been investigated and mapped. Much of this work was inspired by the late Curtis F. Marbut, who translated Glinka's book into English and adapted the ideas it contained to his own work. But, whereas the Russians had developed the classification of soils in broad climatic zones, Marbut elaborated methods for the detailed investigation of local soil types in small areas even down to the farm and the field. His work had a great influence in stimulating soil survey investigations in this country, where there is now a well-developed service. The Soil Survey of England and Wales is based on Rothamsted Experimental Station and that of Scotland on the Macaulay Institute for Soil Research. The whole of the work is supervised by a Soil Survey Research Board recently set up by the Agricultural Research Council. Most of the Dominions have had soil survey services for some time.

Soil surveys are essential wherever large projects for the development of land are contemplated. No such project should be attempted without a previous soil survey. Recent instances of disastrous results from want of this precaution have occurred. It is interesting to learn from a recent BBC talk that the prelude to the erection of a new dam in North Queensland capable of dealing with 5,000,000 acre-feet of water, will be a full survey of all the various soil types in the area which would be irrigated. Investigations will then be made of the capability of the land for growing crops, the most suitable crops and the crop rotations for each soil. This admirable procedure will be repeated in the case of similar projects at present under consideration.

This is only one example of the endless possibilities for the application of soil science to world food problems. Even our existing knowledge, if properly applied, could have an enormous result in raising the level of food production, but much more knowledge is needed for the fullest effectiveness in the utilisation and conservation of all the world's soils. Research must be extended and intensified. At the Royal Society Conference on Empire Science, not long ago, emphasis was laid on the lack of facilities for research in soil science in the British Commonwealth. Existing research stations and universities are hampered not only by lack of room but also by shortage of trained workers. An increase in the facilities for teaching the subject in our universities is, therefore, an urgent necessity. Help towards solving the problem of the world's food supply is surely of vital importance. The first step towards the peace of the world will be taken when that problem is solved. The way to that end is clear.

(Fig. 1 comes from *Science in Progress* (6th Series, 1949), by courtesy of Yale University Press).

READING LIST

Mother Earth (Murby, 1947), by G. W. Robinson. *Good Soil* (English Universities Press, 1944), by S. G. Brade-Birks. For Schools: *Lessons on Soil* (Cambridge University Press, 1950), by Sir E. J. Russell. For advanced study: *Introduction to Soil Science* (Melbourne University Press, 1948), by G. W. Leeper. *Soils* (Murby, 1949), by G. W. Robinson. *Soil Conditions and Plant Growth* (Longmans, 1950), by Sir E. J. Russell and E. W. Russell.

* Particularly insofar as property is concerned.

Hormone Effects in Plants

E. S. J. HATCHER, Ph.D.

MANY readers may have heard about, or even used, growth-regulating substances for stimulating the rooting of cuttings, for removing weeds in their lawn, or for improving the 'set' of their tomato plants, but relatively few will be familiar with the events leading to the discovery of the natural hormone known as auxin, or with the new knowledge which promises to transform agricultural and horticultural practice. This knowledge is accumulating at a great rate; a recent survey citing fifteen hundred references is a remarkable tribute to the rapid development in this field since 1935 when the first synthetic plant 'hormone' was made generally available.

Sachs's Hypothesis

The story of plant hormones opens over eighty years ago when the great plant physiologist Sachs postulated the existence of special substances to start and control the growth of the various organs of a plant. He thought that different substances were required for different organs; that there were special root-forming compounds, leaf-forming compounds and so on, which were present in amounts too small for ordinary chemical detection, and which moved about the plant in a directional or polar manner; thus he suggested that root formation at the base of a cutting followed the accumulation in this region of the root-forming substance; that side buds were inhibited in their growth by a substance moving down from the stem apex; and that flowering and fruiting could proceed in the dark if leaves elsewhere on the plant were in the light, indicating such leaves to be the source of a flower-forming substance. Sach's remarkable insight into the nature of growth regulation and plant development could not be fully appreciated, however, until much later.

Success in physiological investigations depends more than is perhaps realised upon the suitable choice of experimental material. The experiments which led to the discovery of special growth substances in the plant illustrate this most effectively, for they concerned essentially the small first 'leaf' of the grass seedling. The coleoptile, as this is called, forms a hollow cylindrical sheath which protects the delicate shoot during emergence from the soil at germination. After a transient phase of cell-division, the coleoptile grows by a process of cell-extension, but soon dies away after the first true leaf has pushed out, for it has by then served its purpose.

The great attraction of the coleoptile was its high sensitivity in responding to the influence of light and gravity by a bending movement. The response to light, or phototropic response as it is called, in the coleoptile of Canary Grass (*Phalaris*) was among the plant movements investigated by Charles Darwin (1880), who showed that bending towards a side light was the response to a stimulus received in the tip and transmitted downwards to the region of bending. By the simple expedient of covering the tip of the coleoptile with a tinfoil cap the bending movement was prevented. Really there are two components of this transmission—that there is downward transmission is obvious from the spatial separation of the perception and reaction regions, while *transverse* transmission at the tip is shown by the directional nature of the response itself. H. Fitting in Germany (1905–7) attempted to locate the path of downward transmission by horizontal incisions in the coleoptile, but this did not stop curvature, so evidently the passage of the stimulus had not been interrupted by cutting.

P. Boysen-Jensen in Denmark (1907–11) showed that the stimulus actually passes across a wound gap when, as in Fitting's experiments, conditions are so moist as to provide an aqueous bridge across it. In drier conditions Boysen-Jensen demonstrated that the wound incision can be an effective means of interrupting the stimulus. Boysen-Jensen further showed that whereas water or gelatine could restore the continuity of transmission after a wound incision had been made, a mica plate preserved discontinuity. Final proof that connection by living tissue between tip and the reacting zone was not essential was obtained with the demonstration that restoration of the faculty for phototropic response in a decapitated coleoptile came when the tip was stuck back in position with gelatine.

The full implication of these experiments emerged from the research of A. Paál in Germany (1914–19). Paál induced curvature in a coleoptile *without* giving it any phototropic stimulation simply by replacing the severed tip so that it was slightly displaced from its former position; he realised that the tip was the centre which regulated growth in the coleoptile, the controlling agent being a chemical substance, which normally diffused downwards evenly on all sides causing symmetrical growth. He concluded that any process which interfered with this uniform downward diffusion led to unequal growth, resulting in curvature; both stimulation by light and unilateral replacement of the severed tip had such an effect. Emphasis thus passed to the regulation of the normal growth process, and Söding (1925) showed that the growth rate of the coleoptile which has been markedly reduced by decapitation is restored almost to normal when the tip is replaced.

The final stage in proving the existence of a special growth-promoting hormone in the coleoptile was to extract it. F. W. Went (1928) succeeded in doing this where others had failed, and he achieved it with a very simple technique. He utilised the property of the hormone to move out of the tip into agar jelly (a property revealed by the experiments of Boysen-Jensen and Paál), by standing coleoptile tips on a plate of agar which became activated. Not only did the blocks cut from the agar produce curvatures in the coleoptile, but a relationship was established between the size of this curvature and the concentration of the active substance. On this relationship Went based his method for assaying the growth hormone.

There quickly followed the examination of a wide variety of materials by Went's test method of using oat coleoptiles. Seubert had already found a growth-promoting substance to occur outside the plant—in malt extract, diastase and saliva. The culture medium on which the fungus *Rhizopus* had been grown was also found to be active, and it was also shown that organic manures, and to a lesser degree soils.

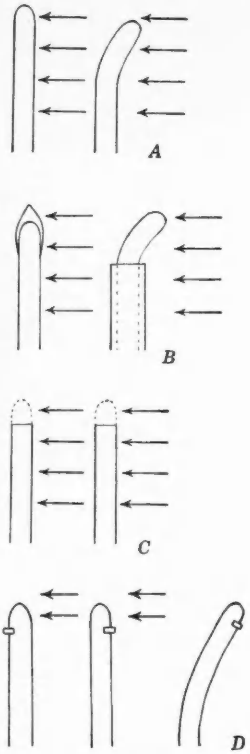
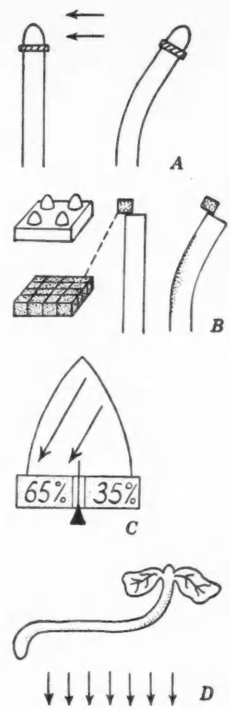


FIG. 1 (*left*).—A. The normal curvature of a coleoptile tip towards the light, due to greater growth on the dark side.
B. When the tip is covered with an opaque cap of silver paper, for instance, light does not reach the cells of the coleoptile tip; the distribution of auxin remains undisturbed, growth remains symmetrical and no curvature results. In the right-hand diagram the lower part of the coleoptile is covered with silver paper; the light now disturbs the downward movement of the auxin, with the result that growth is unsymmetrical and curvature results.
C. Cutting the tip of the coleoptile renders the coleoptile incapable of responding to one-sided illumination.
D. If an incision is made and a piece of mica inserted in the cut, the passage of auxin is disturbed: when the mica is inserted on the illuminated side the coleoptile grows towards the light; inserted on the opposite side no curvature results.

FIG. 2 (*right*).—A. A coleoptile has been decapitated and then the tip has been stuck back on with gelatine. The gelatine is no barrier to auxin movement, and so such a coleoptile is able to respond to one-sided light as does a normal coleoptile.
B. In Went's experiments tips of coleoptiles were placed on agar jelly. Auxin diffused into the jelly, which was then cut into blocks. An auxin-impregnated block attached to one side of a decapitated coleoptile produced more rapid growth on one side and hence curvature in the direction indicated.
C. A coleoptile tip is placed on two agar blocks separated by a thin metal barrier (to prevent diffusion from one block to the other). The tip is then illuminated from one side; the result is unequal distribution of the auxin, the concentration of which is highest in the side away from the light.
D. Geotropic curvatures are also explained by uneven auxin distribution due to gravity. (*After W. W. Robins.*)



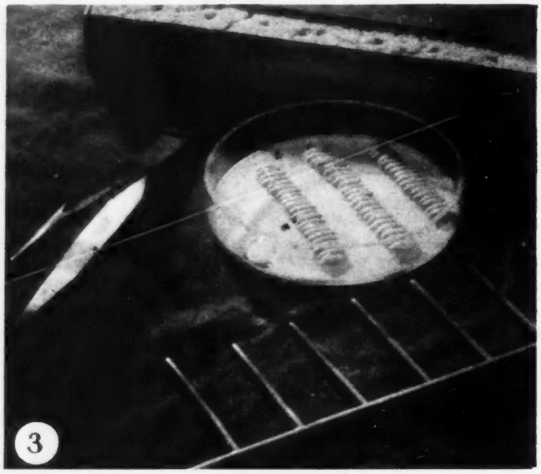
yield measurable quantities of some growth-promoting substance. The principal chemical studies, however, were pursued in Holland by F. Kögl and colleagues, who in 1933 reported the isolation of a pure active substance from human urine which they called *auxin a*. (They had already introduced the general term *auxin* for substances causing the growth reaction in the oat coleoptile.) *Auxin a* was identified as a hydroxy-acid with the formula $C_{18}H_{32}O_5$; a similar substance, *auxin b* (a keto-acid with the formula $C_{18}H_{30}O_4$), was identified in malt and in the oil from the maize germ, the latter source being of direct plant origin. These physiologically active compounds were regarded as characteristic of higher green plants, and Kögl, reasoning from indirect evidence, concluded *auxin a* to be native to the coleoptile.

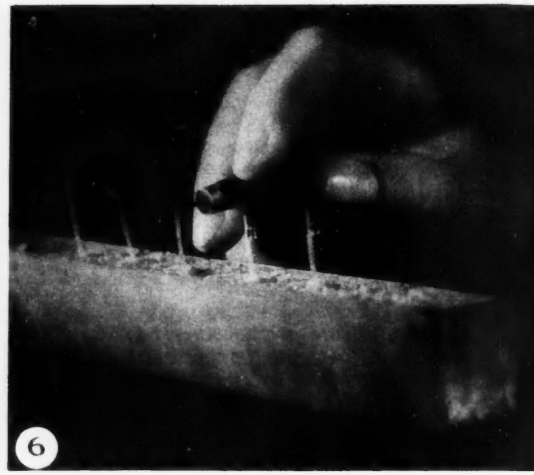
The discovery of a third active substance of quite different chemical constitution introduced a complication. This was isolated from urine and was identified as indolyl-3-acetic acid, $C_{10}H_9O_2N$, a chemical known since 1885 when chemists isolated it from fermentation products; further it was shown that this acid was identical with rhizopin, the growth-promoting substance produced by *Rhizopus*. It was now called *hetero-auxin* not only to show chemical disparity from *auxins a* and *b*, but in the belief that it was quite foreign to green plants. That it had strong physiological activity was regarded with some interest, but always with the sense of not being the real thing. Yet it was this substance which opened up the field of chemical synthesis leading to the extensive use of synthetic growth-regulating substances.

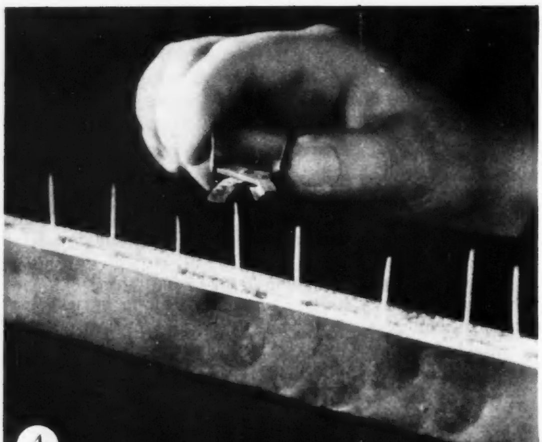
Auxin may be defined as a plant hormone which causes the specific growth reaction measurable by the curvature of the oat coleoptile. It has been shown that *chemically* the auxins form a small group of heterogeneous substances, all of which conform to this definition of physiological activity, though apparently not by their natural occurrence in the plant; for while *auxin a* was deduced to be the natural auxin of the coleoptile, and *auxin b* was isolated from a pure plant oil, *hetero-auxin* was believed at that time not to occur in the green plant. Physiologically, however, auxin has been studied without any reference to chemical form (so that the physiological literature refers to 'auxin', when the chemists would say 'an auxin'). In such studies it would have been impracticable to distinguish between the different auxins as a routine measure, and it is in the physiological sense, therefore, that the term 'auxin' is used in the present context.

Biological assay depends upon the characteristic action of auxin as regulator of cell-extension in the coleoptile. In darkness the coleoptile grows straight upwards when its auxin is uniformly distributed in a transverse plane. Curvature induced by unilateral illumination, or by gravity when the coleoptile is placed horizontally, is then caused by unequal distribution of auxin, the side with more auxin growing more rapidly, i.e. the dark side in the former instance, the lower side in the latter. Thus growth movements of this nature in response to stimulation by light or gravity are seen to be variations of the normal growth pattern induced by particular auxin distributions.

This action of auxin is probably only one of its functions

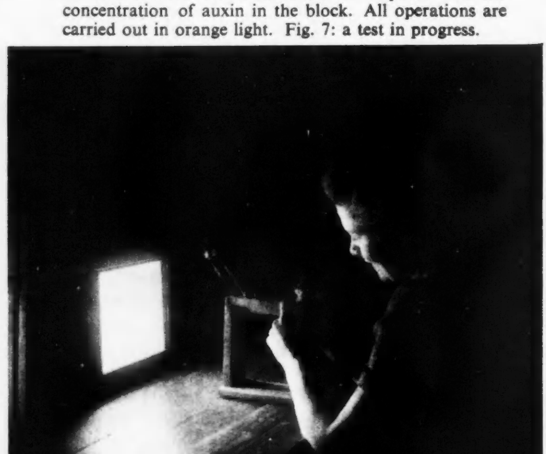






FIGS. 3–7.—*WENT'S COLEOPTILE TEST METHOD FOR AUXIN.* The test is carried out in chambers kept at constant temperature of 25°C. and high humidity. Seedlings of a special variety of oat ("Victory") are used. These are germinated on moist filter-paper in glass dishes exposed to orange light which does not lead to any phototropic curvature. When one day old the seedlings are planted in trays of sand using a multiple brass dibber (Fig. 3). At 3 days the coleoptiles are ready for use.

The stages of the test are shown diagramatically in Fig. 8 (on opposite page) which shows first and second decapitations (*b* and *c*); application of the agar block (*d*); the curvature response to any auxin in the block (*e*). In Fig. 4 first decapitation is shown in progress; this removes the extreme tip of the coleoptile, so taking away the coleoptile's source of auxin. In Fig. 5 the various stages of the second decapitation are shown—the breaking away of a complete cylinder of coleoptile tissue after a side incision, a firm pull upwards to break the leaf inside at its base, partial removal of the leaf leaving a small piece protruding to act as a support for the agar block, which is shown being attached in Fig. 6. After 90 minutes a shadowgraph is taken of the coleoptiles. There is close relation between mean curvature of response and the concentration of auxin in the block. All operations are carried out in orange light. Fig. 7: a test in progress.



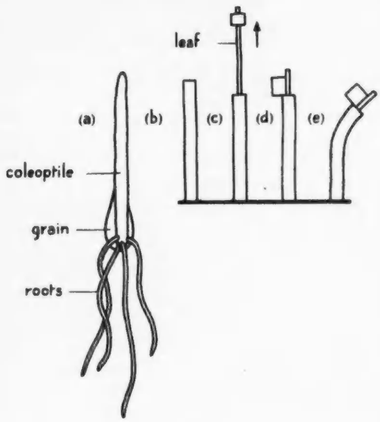


FIG. 8.

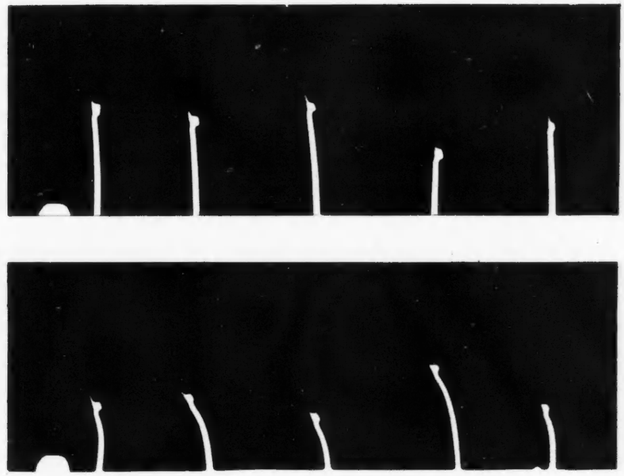


FIG. 9.—Shadowgraphs of coleoptiles; the blocks attached to the top row of coleoptiles contain no auxin; the coleoptiles below have responded to auxin present in the attached blocks.

in the plant, but it was confirmed by the close relationship between applied auxin and growth response in the decapitated coleoptile. With decapitation and the removal of the auxin source, growth immediately subsides, but is continued almost without check if the tip is carefully restored to its original position. 'Without auxin, no growth' became an accepted adage, with the coleoptile proving highly sensitive in its response. Thus if an agar block containing indolyl-acetic acid at a concentration of one part in twenty million is applied unilaterally, an appreciable curvature (15°) results in 90 minutes; in other words, 1 gram of the acid can cause this amount of curvature in a total number of coleoptiles approximately seven times the world's human population. The auxin molecules are, of course, not the prime materials for growth, but operate by regulating growth.

The initial studies of auxin were made in Holland, Denmark and Germany, and concerned not only the physiological action of the hormone but its distribution in the plant. Typical problems concerned the actual source of auxin in the coleoptile, and the nature of its movement. From Europe the hub of auxin research moved with Went to America, where he collaborated with K. V. Thimann in writing a classical monograph on plant hormones. It was also in the U.S.A. that the exploration of synthetic growth substances brought fame to the Boyce-Thompson Institute for Plant Research, particularly to the names of A. E. Hitchcock and P. W. Zimmerman.

The earlier studies soon demonstrated the general occurrence of auxin in all plant parts: stems, buds, leaves, flower-stalks, pollen and—though in minute amounts—in roots. The methods of testing were:

(1) *direct collection* of auxin from a freshly cut plant surface into an agar plate (which was afterwards cut into blocks for application to the coleoptile).

(2) *indirect extraction* by solvents such as water alcohol, chloroform and ether.

The first method was appropriate for actively growing tissues, but sometimes the second was the only practical method, with ether proving the most generally useful solvent. The results showed that auxin was linked with many phases of plant development, and led to the more detailed investigations of recent years. Two of these have been concerned with the cereal grain, and with the growing woody shoot.

The auxin relations of the cereal grain were of great interest in considering the source of auxin in the coleoptile itself, but it was research on ear development in cereals which led to systematic auxin assays by Dr. E. S. J. Hatcher of the East Malling Research Station. Vernalisation treatment of the germinating rye grain at low temperatures had been studied in this country by F. G. Gregory and O. N. Purvis since 1932, and all their evidence ran counter to an auxin 'theory' of the phenomenon put forward by N. G. Cholodny. According to this 'theory' the induction of earlier ear formation in the winter variety (making it behave like the spring variety) resulted from auxin accumulation in the embryo during the vernalisation treatment. No evidence of this was, in fact, found by Dr. Hatcher. His experiments disclosed that more auxin can be extracted from the grain by using water instead of alcohol or ether; the yield of water extraction varied considerably and suggested the release of active auxin in the presence of water. A weak alkaline solution gave further large increases of auxin, this pointing definitely to its release from a precursor that was inactive; it was found too that the proportion of precursor to auxin rose sharply during ripening of the grain in the ear. The auxin in the grain was shown to be located in the aleurone layer (the region of protein storage) and was most concentrated adjacent to the embryo. Other parts of the rye ear were likewise examined for auxin, which was also found in the anthers before the pollen had ripened.

The cereal grain studied by G. S. Avery, Jr., and colleagues in America was maize, from which phenomenal yields of auxin were obtained, again with the copious release of auxin by alkaline solutions. This more than hinted that the auxin involved was not *auxin a* or *auxin b*

but *hetero-auxin*, being later confirmed by chemical isolation from the grain itself. Already the presence of indolyl-acetic acid in higher plants had progressed far beyond a suspicion, from this time it became more and more apparent that *hetero-auxin* occurred extensively in flowering plants, and recently its isolation from the coleoptile has been reported by S. G. Wildman and J. Bonner.

The growing shoot presents a more complicated auxin story, and at East Malling the long vegetative shoots of apple and plum rootstock varieties are under study by Dr. E. S. J. Hatcher. Small stem pieces are ideal for direct auxin collection, and using a standard length of section and collecting for a standard time period, surveys have been made of free-moving auxin along the stem throughout growth. At the actively growing tip the auxin value is moderately high, falling to a much lower level in the young expanding internodes,* rising to a second peak in the internodes immediately below these, finally declining again in the lower shoot. With the onset of dormancy in the woody shoots the auxin values diminish, eventually becoming so low as to fall below the sensitivity of the coleoptile test. The important feature of this distribution is the position of the lower peak, for when the leaves were examined it was found that only the youngest growing ones at the tip contained auxin.

The dormant shoot thus contains no free-moving auxin, and renewal of growth in the spring is to be related to its release from a stored substance. Auxin has in fact been extracted from dormant stem tissue, and the relationship between active and stored auxin is at present being examined throughout the development of the shoot.

Another outcome of these stem investigations is an appreciation of the potential physiological significance, not only of growth-promoting substances, but of growth-inhibiting substances as well. Quite a common experience with ether extraction is that inhibiting effects interfere with the direct expression of auxin activity. By introducing a known concentration of indolyl-acetic acid into the agar block it is possible to measure such inhibition as a reduction in coleoptile curvature, what is measured being a net effect between inhibitor and auxin. Every auxin determination may be considered as such, though the relative amounts of auxin and inhibitor vary over quite wide limits; thus apple shoots are so rich in inhibitor that over a large part of the dormant winter period no auxin can be detected by extraction, whereas with plum shoots no inhibitor is evident and auxin is extractable throughout dormancy.

Synthetic Growth-regulating Substances

The identification of hetero-auxin as indolyl-acetic acid had two immediate and far-reaching repercussions; for the first time a synthetic growth substance was available in relatively large quantities, and experimentation with it could be developed on a big scale. Simultaneously the organic chemist initiated the synthesis of a whole array of similar and related compounds with the aim of exploring the relationship between molecular pattern and physiological activity, and of building molecules of still greater potency.

The first horticultural use of growth substances was as an aid to the rooting of cuttings, for not only could the rooting process be accelerated but many more roots could be stimulated to develop. Indolyl-acetic acid was reasonably effective, but was surpassed markedly by two other compounds, indolyl-3-butyric acid and α-naphthyl-acetic acid, these still being the standard rooting growth substances, though certain other compounds such as 2,4,5-trichlorophenoxy-acetic acid are beginning to come into use.

Many hundreds of species and varieties of plants of all kinds have given a positive response to growth substance treatment and yet, in this country at any rate, their routine use is very limited. The reasons for this may be apparent, but are none the less regrettable. The propagator's art is an ancient one and tradition dies hard, so that when shy-rooting cuttings did not always respond readily to growth substances, the latter's beneficial influence on the great majority of subjects for propagation was overshadowed. Quite erroneously it was said that the use of growth substances was a 'cover-up' for the bad propagator. Sachs, it will be recalled, thought that the cutting roots following the accumulation of a root-forming substance at the base; yet from the marked stimulation on rooting of an external supply of growth substance it is evident that natural auxin accumulation does not usually reach optimal proportions. With regard to technique the cutting may be treated by immersing its base in a dilute aqueous solution for about one day, or by dipping it momentarily in a powder or alcoholic solution. The alcoholic dip method is fast finding favour as a rapid and reliable technique.

The pruning of plants is another horticultural practice of great antiquity, with its basic principle that the removal of some buds on the plant is followed by the development of others which otherwise would remain dormant. A bushy habit can thus be encouraged by the pruning away of leading terminal shoots: indeed the behaviour of a single shoot typifies the general effect, for while the terminal bud is growing actively the side buds below it remain quiescent, but remove the terminal bud and several side buds grow out. This inhibiting power of the terminal bud over the lateral bud was regarded by Sachs as evidence for the existence of special substances in the plant, and, as we have seen, the tip of a growing shoot is an auxin producing region. There is no doubt, therefore, that bud inhibition is an auxin phenomenon, and this can be readily demonstrated by applying paste containing a growth-promoting substance to the decapitated shoot, this displaying for a time a similar inhibitive power. The physiological mechanism of this inhibitive effect is still obscure, however, and has in fact become one of the classical auxin problems.

Direct inhibition of buds by growth substances has also proved possible in certain cases, and one valuable agricultural use of such an effect is the control of sprouting during the storage of potatoes using the methyl ester of α-naphthyl-acetic acid as the active substance. The delay of fruit-bud opening by a short period in order to minimise the risk of frost damage has been found a much more difficult task, though a limited effect was reported of a high concentration spray (800 parts per million) of α-naphthyl-acetic acid given the previous summer. In general the regulation of bud growth by synthetic growth substances is still in an early stage of development.

The natural shedding of leaves, petals and fruits by the plant is an active physiological process located in a zone of cells known as the abscission layer. In this abscission or

* Internodes are the lengths of stem between the leaves.

separation layer, adjoining cells become parted as a result of the disintegration of their middle lamellae (the first layer of their walls to be laid down), and it was the observation that cuttings treated with growth substance retained their leaves better than untreated cuttings that pointed to an auxin mechanism. Abscission of a leaf or fruit stalk can be induced simply by removing the leaf or fruit, or subsequently delayed by the external application of a suitable growth substance. Fruit drop prior to picking thus became a growth substance problem, and pre-harvest sprays are now being applied on an extensive scale, particularly with certain varieties of apple and pear. A spray of α-naphthyl-acetic acid at a concentration of 10 parts per million given about ten days before harvest is the normal treatment, this having the effect of delaying fruit drop sufficiently to allow maximum picked crop.

Auxin has been extracted from various fruits, particularly from their seeds, the normal requisite for fruit development being pollination and seed setting. This is not an absolute rule, however, and natural seedless varieties include banana, navel orange and cucumber. Artificial fruit-set induced by growth substance sprays has now enabled a range of fruit varieties to develop in the absence of pollination, holly berries, beans, strawberries and tomatoes being examples. Such sprays may be given to supplement normal pollination, the most extensive use being with tomato which responds readily. Indolyl-acetic acid has a very weak action compared with β-naphthoxy-acetic acid (used at a concentration of 50 parts per million), or with 2,4-dichlorophenoxy-acetic acid which is potent at only 1 p.p.m. and causes malformed fruit at higher concentrations. The apple is highly resistant to fruit-setting sprays.

Physiological death of cuttings by over-stimulation with a growth substance is to be avoided; death of weed plants by similar action is highly desirable if it can be accomplished without harm to the crop. This has been achieved with selective hormone herbicides, the researches of G. E. Blackman and colleagues in Britain deriving from the observation of W. G. Templeman that α-naphthyl-acetic acid was toxic to charlock but not to oat seedlings. Toxicity of this nature is distinct from the contact injury effected by the orthodox weedkiller, and is a slow process taking days or even weeks, the growing regions being the most sensitive. Its selective action is an excellent example of the differential response of plants to growth substance. Another is afforded by the resistance of the apple to fruit-setting spray and root stimulation, as contrasted with the ready response of the tomato to both of these, together with its proneness to formative effects including root formation on aerial stems, malformed leaves, and by using 2,3,5-tri-iodo-benzoic acid, the induction of blossom trusses. How fortunate was it that grass and cereal happened to be resistant to the herbicidal action of growth substances, for now millions of acres are sprayed to control weed species.

The substituted phenoxy acids came to the fore as weedkillers, two in particular, 2,4-dichlorophenoxy-acetic acid* and 2-methyl,4-chloro-phenoxy-acetic acid†. The violence of their action is extreme, though at very low concentrations rooting, abscission and fruit-setting effects can be obtained without injury. The usual method of application is by spraying, and transport of the herbicide to other parts of the plant is an essential feature of its action. So while the non-physiological weedkiller destroys the aerial parts quickly and effectively this has no lasting effect on the perennial plant; whereas the growth substance with its slow toxicity is transported physiologically from the shoot, whose main purpose is to ensure entry to the perennating organs, not otherwise reached. It will be appreciated why 2,4-D is so effective for weed control in lawns.

There is an intriguing contrast between the unlimited diversity of synthetic growth-regulating substances, applicable to the plant at any level of concentration, and natural auxin with its narrow physiological concentration range. Yet all the effects of the former, the more important of which have just been reviewed, are expressions, though sometimes in exaggerated form, of auxin action. Auxin is in fact concerned in every phase of plant growth and development, though of auxin mechanism much is still unknown. Sachs postulated a series of different substances controlling development, but so far the existence of hormones other than auxin, even if probable, has not been proved directly. What is universally accepted nowadays is the hormonal nature of developmental control in the plant. Against this it has to be admitted that the part played by auxin cannot, even now, be adequately assessed; so while no simple auxin explanation may hold for any given developmental behaviour in the plant this does not necessarily imply that auxin is not involved. For the time being it is wiser to accept auxin as a general growth regulator, of universal occurrence throughout the broad divisions of the plant kingdom, and therefore as a very remarkable substance, worthy of all the attention which it now enjoys.

The implication of such a viewpoint is that all plants, in all environments, are subject to some degree or other to the physiological action of the growth substance. Thus every kind of plant culture, whether it concerns field or garden, forest or water, falls within the compass of these compounds. Little wonder then that physiological insight lags far behind empirical observation; for if the apparently simple action of auxin in regulating plant growth by cell-extension is not properly understood, much less the more subtle ways of auxin in correlated growth, how infinitely more difficult to comprehend the effects of a diversity of synthetic compounds? The comforting thought to end with is that such physiological intricacies boil down to very simple practical procedures, which may date, not from the introduction of the synthetic growth substance fifteen years ago, but from those times of old when the propagator inserted a wheat grain to aid the rooting of his cutting.

* Known as 2,4-D or DCPA to farmers and horticulturists.
† Known as MCPA.

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Far and Near

Nobel Prize for Chemistry

The Nobel Prize for Chemistry for 1950 has been shared by Prof. Otto Diels, who is 75 and has been a professor at Kiel University since 1916, and Prof. K. Alder, a pupil of Prof. Diels and now professor of chemistry and chemical technology at Cologne University. The award was made for their discovery in 1928, of the diene synthesis, now commonly called the 'Diels-Alder reaction'.

This is a reaction of unsaturated compounds which occurs with surprising ease, often at room temperatures, and sometimes explosively. Typical examples are the combination of butadiene with acrylic aldehyde to produce tetrahydrobenzaldehyde, or of isoprene with maleic anhydride to produce methyltetrahydrophthalic anhydride. A powerful synthetic method for producing cyclic organic compounds is thus available. *Nature* has pointed out that it has contributed to knowledge of polymerisation processes whereby valuable plastics have been obtained, and probably it accounts for the formation of many chemical compounds in plants.

Prof. Diels has carried out work of first quality over a surprisingly long period. The double ketene $O:C:C:C:O$, known as carbon suboxide, was prepared by him as far back as 1906 by the decomposition of malonic acid with phosphorus pentoxide. From that time on he has made major contributions throughout the field of organic chemistry.

Production of Terylene and Ardil

The two new textile fibres, Ardil and Terylene, should be in production in the comparatively near future.

Ardil, a wool substitute made from groundnuts, will be produced in a factory at Dumfries. I.C.I. state that by February 1951 the project will be sufficiently advanced to start production at about a quarter of the factory's total capacity.

Terylene, which is chemically different from any other synthetic fibre, was discovered in 1940 in the laboratories of the Calico Printers' Association by two chemists, Whinfield and Dickson. I.C.I. obtained from the C.P.A. the manufacturing rights for the whole world outside the U.S.A. and has been responsible for the development work on Terylene, which has been carried out in the laboratories of its Plastics Division at Welwyn Garden City. A pilot plant with a capacity of several hundred tons per annum has been erected in Hillhouse, Lancs., and this plant, in addition to providing technical data for the design of the large-scale plant, is producing material for development work by leading firms in the British textile industry. Construction is now to begin on a full-scale production plant with an annual capacity of 5000 tons of Terylene. This substance is a condensation product of ethylene glycol and terephthalic acid, which will be available from the new oil-cracking plant at Wilton, where the Terylene factory will also be situated.

Fish Discoveries, By-product of Bikini

Biology was very well represented at the Bikini atomic-bomb trials, for the reason that it was decided to collect as much evidence as possible about the effect of the explosions on the fauna and flora of the atoll. The fish population received particular attention, and many new species were discovered. To date 481 species have been distinguished among the fish specimens collected there, and of these 79 have never before been described, according to Dr. Leonard P. Schultz, curator of fish at the Smithsonian Institution in Washington. The work of sorting the collection is still far from complete. Most of the new species are similar in appearance to forms already known. Some of the Bikini fish, however, are fantastic according to Dr. Schultz. Among them is one of the smallest in the world, a member of the blenny family, only 15 millimetres long. It lives in crevices of the coral under violently churning waters.

Carnivorous Fungi versus Plant Pests

Apropos the article on Carnivorous Fungi (Discovery, September 1950), a reader writes to ask whether predacious fungi might be used to combat the eelworm which ruins potato crops. Dr. C. L. Duddington replies to this question as follows:

The biological control of eelworms parasitic on crop plants has been attempted by Linford and his co-workers in Hawaii. Two principal methods were used:

(*a*) The addition of culture of suitable predacious fungi to test plants grown in pots.

(*b*) The addition of organic matter—e.g. chopped pineapple tops—to soil, in order to encourage the growth of predacious fungi assumed to be already present.

The experiments were carried out during the latter part of the 1930's. The results suggested that some measure of control of the pest was achieved, but it must be pointed out that the experimental methods used were open to criticism, so that no conclusions can be drawn about the possible utility of the fungi. The suggestion that the activity of predacious fungi could be augmented by the use of compost has been made more than once, but no experimental evidence has so far been produced that this is so.

Predacious fungi vary greatly in their virulence towards eelworms, and the same fungus may vary at different times and under different conditions. The possibility of controlling eelworms simply by the application of compost, without making certain that the appropriate fungi are present in sufficient quantities, does not seem very hopeful. This does not mean, however, that biological control by predacious fungi is impossible, given the right methods and the proper scientific approach to the problem. In my opinion, more work should be done on this, especially in regard to the control of eelworms under conditions of intensive cropping, such as where tomatoes are grown on a large scale under glass, for biological control methods would probably be easier to apply under glass-house conditions than in the field. It must be emphasised, however, that any such attempts should be preceded by careful research on the fungi themselves, with a view to finding out the best species to use and the right method of application. Haphazard dosing of crop plants by workers who are not sufficiently familiar with the habits of predacious fungi is likely to do more harm than good, but it is my view that properly organised research over a sufficient period of time might well yield a worthwhile dividend.

Australian Flowers at Kew

By midsummer a large new greenhouse will have been completed at Kew Gardens to house Australian flowers. This opens up the prospect that visitors to Kew will soon have the opportunity of becoming familiar with the Australian flora, the members of which are comparatively unknown in Britain except for the species of wattle (*Acacia dealbata*) which is sold by florists and barrow boys around Christmas. This flower is imported from the Riviera, where the climate is more suitable for growing Australian plants than is the British climate.

A collection of Australian plants which will go into the new house has been raised at Kew from seed sent over from Pellanza in Italy, where Capt. Neil McEachearn maintains a fine botanical garden. This will be supplemented by material sent over by the Australian Botanical Gardens.

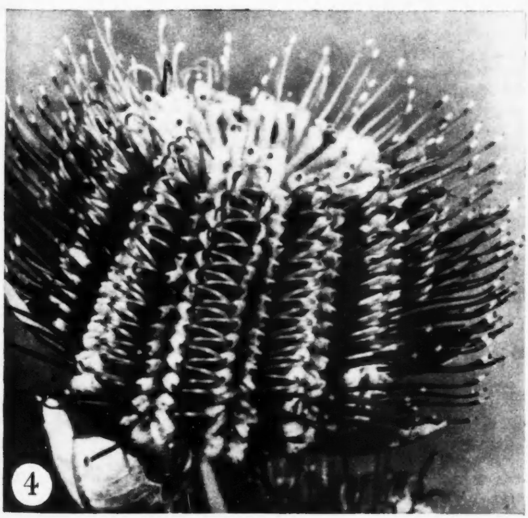
The pictures opposite show some of the characteristic Australian flowers which one may now expect to see grown at Kew. For reasons connected with the difference in the British and Australian climates and with the fact that the rhythm of Australian plants leads to their flowering at a time when our plants are dormant, it seems unlikely that a fashion in Australian flowers can spread to British gardens, though there are many fine garden species among the antipodal genera such as *Eriostemon*, *Leptospermum*, *Callistemon* ('Bottle-brush'), *Epacris* and *Boronia*.

"Fish Migration"

In the article "Fish Migration" we published last June, some passages were quoted from *Fishlore* by A. F. Magri MacMahon. Acknowledgment of this source was inadvertently omitted from the typescript of the article, and the author wishes to express regret for this omission to Mr. MacMahon and Penguin Books, the publishers of *Fishlore*.

1. A typical wattle (*Acacia*).
2. Flowering gum, one of the Eucalyptus species.

3. Fuchsia heath (*Epacris longiflora*).
4. *Banksia coccinea.*
5. Kangaroo paw. (*Anigozanthus manglesii*).



Medical Aspects of Atomic War

The December 1950 number of *The Practitioner* is almost entirely devoted to a symposium on the medical aspects of atomic warfare. In preparing it the editors had the expert advice of Sir Ernest Rock Carling, consultant adviser for Casualty Services to the Home Office, and the result of their collaboration is the most exhaustive monograph on the subject so far published in Britain, comparable in importance to the September 1950 issue of the *Bulletin of the Atomic Scientists* dealing with civil defence against atomic attack.

At a press conference called in connection with the publication of this special number of *The Practitioner*. Sir Ernest Rock Carling made an emphatic statement about biological warfare, which is doubly significant since it is almost the first authoritative British statement about the hazard to be faced if biological weapons were to be used in any future war. Approaching this question as a person concerned with British Civil Defence he said: "It is extremely doubtful whether biological agents can in fact be distributed so as to produce the desired results from the enemy point of view. The development of antibiotics has gone on at such a pace that we have efficient treatment for practically all the biological agents that can be used against us. There is only one real danger, and that is sabotage; the most serious form of sabotage would be that of water supplies. In the last war all water supplies were heavily chlorinated, and it is difficult for biological agents to get past the chlorine in the water."

Amateur TV Transmission

The decision of the Postmaster-General to grant licences for transmitting television signals for experimental purposes may lead to a revival of interest in home construction and experimenting which waned with the introduction of electronic television. It must be remembered that in the early days of Baird's low-definition television the audience was almost entirely composed of enthusiastic amateurs who had assembled their own receivers. The home-constructor market has been growing again during the past few years and may be expected to flourish still further when it is possible to send and receive pictures as well as sound.

At present the wave-bands allocated to experimental work are limited to 2300–2450; 5650–5850 and 10,000–10,500 megacycles, and such high frequencies will tax the skill of the experimenter to produce good results. The cost of the camera tube will also deter many, although it is possible to transmit a good 'still' picture by scanning a transparency with a high-voltage cathode ray tube.

Already an Amateur Television Transmitter's Club is in existence, and amateur-constructed camera equipment was recently demonstrated successfully at Letchworth on closed circuit by Mr. I. Howard, of Bedford. Although this was not the first amateur television transmission (for Messrs. Gardner and Wilson transmitted pictures over a closed circuit at Imperial College in 1934), Mr. Howard is to be congratulated on his enterprise and on being the first to obtain an amateur's transmitting licence.

Why be a Science Teacher!

In our editorial in the November 1950 issue we referred to some observations on the supply of science teachers for schools which were made at the conference organised by the F.B.I. Sir Wallace Akers has asked us to make it clear that the statement attributed to him was made when he was reporting the discussion of the Discussion Group of which he was chairman. He entirely agrees with the view he expressed in that capacity, but feels it should be made clear that he was expressing a *collective* opinion and not just a personal view.

A Book of Scientific Biographies

The biographies of famous scientists which I.C.I. published in their series of prestige advertisements have been collected together in the form of a 164-page book entitled *Ancestors of an Industry*. A limited number of copies are available free to the heads of Science or Chemistry Departments in schools if they make application to: Central Publicity Department, Imperial Chemical Industries Ltd., 42, Hertford Street, London, W.1.

Lecturers for Junior Science Societies

The British Association desires to do whatever it can to help and encourage existing science clubs, to assist new clubs which may be formed in response to a real demand, and to promote co-operation between kindred groups. One specific way in which it is prepared to help School and other Junior Scientific Societies is by suggesting the names of suitable speakers. The Association of School Natural History Societies exists to help School Societies concerned with the biological sciences, many of which have sought its advice regarding speakers. The British Association is ready to supplement this existing service by suggesting speakers on subjects which are covered by its Sections. These are: Physics and Mathematics, Chemistry, Geology, Zoology, Geography, Economics, Engineering, Anthropology and Archaeology, Physiology, Psychology, Botany, Education, and Agriculture.

Requests for such assistance should refer to this notice in Discovery and be addressed to The Secretary, British Association, Burlington House, London, W.1., as far ahead as possible of the fixture it is desired to arrange. Letters should indicate the subject on which a lecture is desired, the proposed time and place of its delivery, and whether the lecturer's out-of-pocket expenses will be met.

Atomic Piles off the Secret List

The Governments of Britain, Canada and the United States have now released technical information about existing low-power atomic piles and the values of pertinent nuclear constants of uranium. This will help in the instruction and training of technicians and scientists and thus contribute to the development of atomic energy for peaceful purposes. Full particulars are being given of GLEEP, the smaller uranium and graphite pile or reactor at Harwell; ZEEP (Zero energy experimental pile), a heavy water and uranium reactor at Chalk River, Ontario; and four of the United States reactors. In addition, certain information will be released about BEPO (British Experimental Pile), the larger of the Harwell piles, and similar reactors in the U.S.A and Canada.

The three Governments are satisfied that the information will not be of material assistance to other nations in the development of military applications of atomic energy. Low-power research reactors cannot be used for producing atomic weapons or power.

Night Sky in January

The Moon.—New moon occurs on Jan. 7d 20h 10m, U.T. and full moon on Jan. 23d 04h 47m. The following conjunctions with the moon take place:

January				
10d 02h	Mars in conjunction with the moon	Mars	2°	N.
11d 08h	Jupiter ,,	Jupiter	0·2°	N.
27d 23h	Saturn ,,	Saturn	4°	N.

The Planets.—Mercury, in inferior conjunction on Jan. 1, is too close to the sun in the early portion of the month to be seen. Later it can be seen as a morning star, rising at 6h 30m and 6h 40m on Jan. 15 and 31, respectively. Venus is an evening star, setting at 16h 45m, 17h 30m, and 18h 20m, at the beginning, middle, and end of the month, respectively. More than 95% of the illuminated disc is visible throughout the month, and the stellar magnitude of the planet is about −3·3. Mars, an evening star, sets about 2½ hours after the sun during January and can be seen in the western sky in the constellation of Capricornus. Towards the middle of the month the planet is a little N. of the two stars δ and γ Capricorni. Jupiter sets at 20h 55m, 20h 10m, and 19h 30m, on Jan. 1, 15 and 31, respectively. The stellar magnitude of the planet varies from −1·8 to −1·6 during the month. Saturn rises at 23h 30m, 22h 30m and 21h 25m, at the beginning, middle, and end of the month, respectively, and can be seen in the constellation of Virgo close to the star η Virginis. Notice the close approach of Saturn to the moon on Jan. 27, already referred to under conjunctions.

Those who are in possession of a small telescope might like to test it on Polaris with the object of detecting its companion. It is doubtful if they will be able to see it with anything less than a 3-in. objective and even with this a clear sky will be necessary, but a lot depends on the observer's eye. Dawes proposed it as a general standard, and affirmed that, provided the eye and the telescope are good, a 2-in. refractor and a power of 80 will find it. He saw it even with a telescope just over 1½ in. in aperture, and it would be interesting to know if any readers can see it with anything less than a 3-in.

The Bookshelf

Sound. By Frederick G. Mee. (Heinemann, London, 1950, pp. 171, with 100 illustrations and 5 plates, 8*s.* 6*d.*)

It is unusual for writers of textbooks on Sound to pay much attention to musical instruments between the extremes of the tuning fork and the organ pipe. In one of the most attractive sections of Mr. Mee's book, however, we are taken through the instruments of the orchestra and introduced to individual members of the strings, woodwind, and brass. On the electrical side we meet the electronic organ, and disc, steel-tape, and film recording and reproduction.

In its 170 pages the book aims at being very comprehensive: an attempt is made to deal with all matters of general interest in Sound, and its connexions with other sections of Physics. Thus, in addition to the standard ground-work, and the mathematical basis of the subject, notes are included on such subjects as valve amplifiers, cathode-ray oscillographs, electric clocks, piezo-electricity, magnetostriction, supersonics, and the accoustics of buildings.

To cover such a vast field in so relatively short a space the author must pay with enforced brevity. This becomes marked in some barely adequate descriptions of rather unusual pieces of apparatus, and an over-brief note on Fourier analysis. In some cases these condensations would be useful to the student only if he were told where to find a full account: but the total lack of bibliography is a sad omission in a book of this type.

There are many sections, however, where the author is not cramped by this emphasis on brevity, and these are clearly and thoroughly explained—particularly those on the Doppler effect and the influence of atmospheric conditions on audibility. The whole is well produced and illustrated, contains a useful collection of examination questions, and is comparatively cheap at 8*s.* 6*d.*

The general technical level is that of Scholarship examinations and early University work. It is thus not suitable as a first textbook on the subject, but forms an excellent bridge between the elementary textbooks and the classical treatises.

S. J. B.

The Story of Animal Life. By Maurice Burton. (Elsevier, 1949; distributed by Cleaver-Hume Press, London, 2 vols., pp. 381 and 423, over 1000 illustrations, £3 3*s.*)

If these books contained nothing but the text they would be well worth the reading. Dr. Burton has set out to provide a comprehensive and authoritative review of the science of Zoology and has succeeded admirably. The first six chapters of Volume I deal with animal life in its more general aspects. Chapter I is largely an introduction to those special properties which distinguish the animal from the plant and the living from the lifeless. Chapter 2 deals more fully with the various methods of asexual and sexual reproduction found at different levels in the Animal Kingdom, and with evolutionary theory. The third chapter is devoted to fossils and includes an account of the so-called 'living-fossils' and of several species that have recently become extinct. Chapters 5 and 6 cover the fields of animal behaviour and ecology, marine life forming the subject of Chapter 6. The remainder of the twenty-three chapters of Volume I deal in systematic order with the Invertebrates: seven chapters are devoted to insects.

The Phylum Chordata provides the subject matter for the whole of Volume 2. One chapter is allotted to the Acraniate forms, four to the fishes, one to the amphibians, two to the reptiles, seven to the birds and eight to the mammals.

On the other hand, if these books contained nothing but the illustrations they would be well worth looking at. The publisher's note claims that these photographs are "almost certainly the best collection that has ever been assembled in a work of this kind". One would have accepted the omission of the modest word 'almost' without demur. At the first reading one is perhaps a little disconcerted by a certain lack of cohesion between the illustrations and the text. This is not to suggest that the illustrations are in any way irrelevant; it is merely that the text makes no direct reference to them and that they do not necessarily illustrate that part of the text appearing on the same page. Subsequent readings however reveal that the fault lies not in the books but in one's approach to them. Had the text been written around the illustrations it could not have stood on its own: had the illustrations, as in a text-book, been subordinated to the text both they and the make-up must have suffered severely. Instead, text and illustrations exist as it were symbiotically between the covers, each enhancing the excellence of the other yet neither depriving the other of any individual merit.

A little praise where praise is most certainly due does not mean that perfection has been achieved. Dr. Burton has included in the text a number of monographs by specialists in certain fields. This, while giving the text added authority, has meant sacrificing continuity of style. This would not have mattered so much if the quality of the prose in these various essays had been on a level with Dr. Burton's. Unfortunately it is not. The style of one that comes to mind can only be described as turgid: through another runs a vein of such elephantine whimsicality that the reader is irritated beyond measure. Another minor blemish is perhaps a reflection of the difficult paper supply situation in this country. These books were printed abroad and, although their general standard of production is commendably high, there is perhaps a larger number of typographical errors than might be expected in a work of this nature produced at home.

These criticisms having been made, one realises that they detract only a little from the solid worth of these two volumes. These books deserve a place in all but the most highly specialised libraries and on the bookshelves of any private person with a mind above detective fiction.

R. P. Hill

Are Workers Human? By Gordon Rattray Taylor. (London, Falcon Press, 1950, pp. 196, 10*s.* 6*d.*)

Mr. Rattray Taylor has undertaken to assess and describe in simple vivid language all that is known about the sociology and social psychology of our working lives. The size of his undertaking may be appreciated from his bibliography—valuable in itself—which consists of some 40 books and about 100 articles.

The result is a work that presents a valuable account of progress, but is a little dangerous in that it claims too much, and in its conclusion, where the discussion is extended to the whole of society, it tends to be a little unreal.

Mr. Rattray Taylor gives a fair picture of many of our social problems of industry, discussing the motives for work, the social relations of the factory and the workshop, as well as frequent causes of discord and possible ways of achieving harmony. All this is done with lively illustration, presented with evidence from studies in Britain and the United States.

His accounts of the importance of status and prestige, of the folklore of industry and of problems of communications are fascinating and impressive. Where the work is weak is in the omission of an adequate account of institutional influences in the culture as a whole: for example, the conflict between men and women, and the young and the old; and conflicts in the culture of certain regions, industries and even firms. Many of these, like that between weavers and power-loom overlookers, are largely independent of life inside the factory.

The influence of our recent industrial history on management, worker, trade unionist and politician is not fully appreciated, perhaps because the author has taken much of his evidence from the new light industries of the south rather than from the older basic industries like coal and textiles. The discussion of the role of trade unions is also very inadequate.

The casual reader may obtain the impression that the two sciences—sociology and social psychology—are more advanced than they are, for Mr. Rattray Taylor does not make it clear how much of what he describes is based on experience, intuition or single case studies, and how little of it has the background of systematic research that characterises the natural sciences. It is nevertheless a valuable account of a developing study.

Dennis Chapman

[*Continued on p. 34*

FIG. 1.—A heavy pneumatic-tyred roller used at the Road Research Laboratory for compacting soils. (*D.S.I.R. photo.*)

The Road Research Laboratory

A. GRAHAM THOMSON

THE objective of road research might be described in seven words: To make roads *better*, *safer* and *cheaper*. On that brief definition road research clearly covers a multitude of activities, ranging from the development of better road-building materials and methods of construction to analysis of human behaviour and traffic flow. Since everybody uses the roads, it is hardly possible to overestimate the benefits to a nation like Britain of a research programme undertaken for the broad purpose of enabling traffic of all kinds to move more safely, expeditiously, economically and comfortably. A mere reduction of 1% in the accident rate would result in a saving to the nation of £1 million a year, though this is a small matter in comparison to the lives that are lost and an infinity of suffering caused by road accidents. Over 1,250,000 workers are directly engaged in maintaining and operating the nation's road transport facilities at an annual cost of £600 million. The cost of maintaining Britain's 180,000 miles of road is about £60 million a year. Against these impressive figures the importance of road research can be realised.

Road research has been described as a joint undertaking in which both scientists and highway authorities are concerned. On the scientific side the numerous problems involved in the provision of better, safer and cheaper roads are investigated at the Road Research Laboratory of the Department of Scientific and Industrial Research. This laboratory has a staff of about 430, including 80 scientists with degrees or equivalent qualifications. Its annual income is about £300,000.

This research unit, which is located at Harmondsworth, Middlesex, has developed from a small testing station set up by the Ministry of Transport twenty years ago. In 1933 the Laboratory and staff were taken over by the Department of Scientific and Industrial Research. It first of all came under the Building Research Station for purposes of administration. In 1936 the present Director of Road Research, Dr. W. H. Glanville, joined the Road Research Laboratory, which became a separate organisation soon after his appointment.

At this time there were two main sections, concerned respectively with concrete and bituminous materials. A few years before the war it became increasingly realised that considerable economies could be effected by stabilising, compacting and draining the soil before the road surface was laid down. A soil section was therefore established in 1937 under the late Mr. A. H. D. Markwick.

When war broke out the Laboratory was called upon to undertake many special investigations entirely outside its

normal sphere. Initially it was concerned with the construction of air-raid shelters and the effects of bombs on buildings. Later on, when emphasis was switching from defence to attack, it carried out investigations on models to examine the effects of explosives on such targets as dams and concrete anti-tank walls. Among the many special problems it studied was the development of rapid methods for laying fighter airfields in forward areas.

The stability of beaches and the crossing of bad ground by heavy tanks were problems of vital importance to military operations. In planning the D-Day landings, for instance, it was essential to ascertain the bearing power of the beaches before the troops landed and the ground over which an offensive was to be launched also required special study. During the war soil samples from operational theatres all over the world were examined, the data collected during these investigations being utilised by SHAEF in planning strategy and in co-ordinating the movement of armies with ground conditions. Most of such 'soil reconnaissance' was done by men who were trained at the Road Research Laboratory.

Tests of all kinds had to be developed for determining the properties and condition of soil as an engineering material, particular attention being given to rapid field tests which could be used by contractors and resident engineers. One of the first requirements in this connexion is an accepted and systematic method of identification and classification, and the Laboratory therefore adopted a technique of classifying soils according to the proportion of particles of different sizes, which in conjunction with other properties gives a useful guide to their behaviour in a road surface.

Since the war the Laboratory has continued its soil research, the essential purpose being to find means of increasing the bearing power of the soil on which a road is laid. It is the soil which actually carries the traffic load, so that any increase in its bearing power will permit a thinner and more economical form of road construction.

If the soil in a road bed is well compacted the foundation is stronger and the risks of road failure are minimised. The extent to which a soil can usefully be compacted depends on its type and on the amount of water it contains; gravels and sands can be compacted to a high density, while clays are the most difficult to compact. The Laboratory compacts samples of all kinds of soil with various types of plant, measuring the degree and depth of compaction obtained with each machine.

Closely associated with these experiments are investigations into the stabilisation of soils with cement, which involves the mixture of a small percentage of cement with pulverised soil. Soil-concrete has an appreciable hardness and resistance to weathering and is much less liable than natural soils to become muddy or slippery in wet weather. The stability of the soil under traffic load may be greatly increased by adding clay, sand or gravel, and so improving the relative proportions of particles of different sizes.

This research work yields no rapid or spectacular results, but consists essentially of the patient classification and study of almost every type of soil, including many Colonial soils as well as British soils. The aim is to build up a vast store of information on soils and methods of treatment, which will lead to more economical road-building and to an improvement of the general standard of dirt roads in the Colonies.

Of Britain's 180,000 miles of road, 100,000 miles are surface-dressed and the annual cost of maintaining the surface of these is about £10 million.

Surface dressing consists of two operations—spraying the tar or bitumen and spreading the chippings either by hand or by machine; the tar acts as an adhesive between the stone chippings and the road surface. The length of life of the dressing depends on the correct amount of tar being sprayed in a uniform film at a rate appropriate to the type and size of the chippings used. In modern equipment the flow of tar may be pressure controlled, but in many sprayers it is governed by the speed at which the machine travels along the road. Improvement in the technique of spraying the tar has, of necessity, had to be achieved by the better use of existing machines. Several simple tests have been developed for measuring the thickness and uniformity of the tar film, and it was also suggested that all sprayers should be fitted with dipsticks and speedometers of a suitable type, so that the operators could know what they were doing. If, as a result of all these measures, the average life of a dressing can be increased from five to seven years, the saving to the country will be about £1 million a year.

Present researches in connexion with concrete roads involve a study of the design and performance of concrete mixers. Concrete is prepared by adding water to a suitable mixture of cement, sand and either gravel or stone chippings. Earlier researches have shown the importance of gauging the ingredients correctly and avoiding the use of excessive water. It was found that the strength of concrete could be greatly increased and cracking could be reduced by using very dry mixes, but these are more apt to stick in the mixer and are more difficult to handle and compact. Concrete only develops its full strength if it is thoroughly compacted to reduce air voids. The Laboratory is investigating the compaction of concrete by vibration, which in turn involves a study of vibrating devices and of the degree to which the various types of vibration are transmitted through the freshly placed concrete. The vibrators may be pneumatically or electrically operated or may be driven by a petrol engine. In road construction the vibrating units are often mounted on a screed, which is a bar perhaps 15 or 20 ft. long placed across the road. Alternatively a vibrating boom may be incorporated in a machine which travels on rails.

So far as performance is concerned, there is little to choose between concrete and bituminous roads, choice being governed largely by the local availability of materials.

Up to four years ago the activities of the Road Research Laboratory were confined to road materials and construction. Now its terms of reference enable it to deal with problems of road safety and traffic flow. Accommodation for the division set up to investigate these matters was found at Langley Hall, Langley, about four miles from the main laboratory. It is in the charge of Dr. R. J. Smeed, who is deputy to the Director of Road Research.

The work of this division falls into two main sections. One section studies police reports on accidents and analyses the circumstances resulting in accidents; it also considers the effects on road safety of any improvements resulting from research. The second section is mainly concerned with the study of traffic flow and road layout.

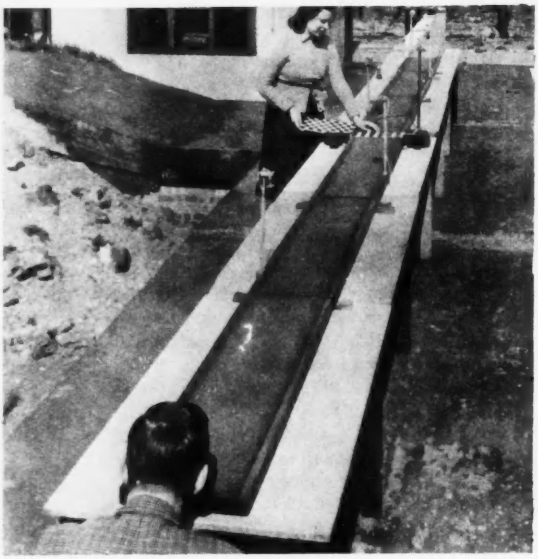


FIG. 2.—Model pedestrian crossing for studying the visibility of different types of marking. (*D.S.I.R. photo.*)

This involves taking censuses of traffic, measuring journey times and traffic speeds, and finding out the amount and type of traffic using each road and the effectiveness with which each part of the network handles the traffic moving through it. Much work has already been done in devising tools suitable for this kind of work such as traffic counters and speed-measuring apparatus. Road intersections and roundabouts are now being studied; this investigation is carried out on a disused airfield where various types of road intersections or roundabouts can readily be improvised. These are fed in various ways with numerous vehicles in succession to provide the traffic, so that the handling power of each type of intersection can be found.

One of the first problems investigated was the marking of pedestrian crossings. Experiments were made with a scale model of a crossing under conditions simulating wet and dry roads by day and by night. The 'carriageway' consists of a level straight section of asphalt carpet 24 ft. long with a crossing in the centre. The observer views the carriageway from the end of the model from a height of $2\frac{1}{2}$ in. above the road surface, equivalent to a full-scale height of 5 ft. (The scale of the model is $\frac{1}{24}$.) Night-time observations are carried out in a dark room. Two classes of lighting were investigated, but in both cases it was found desirable to increase the brightness of the crossing by a special floodlight suspended above the centre. The most conspicuous patterning for a crossing was found to consist of black and white stripes parallel with the kerb.

The next step was to determine whether the behaviour of motorists and pedestrians was affected by the striped crossings, and observations were therefore made by trained observers on experimental 'zebra' crossings laid down at various centres. The index used in assessing the results is the percentage of people crossing the road who use the crossing. Though the results are still inconclusive some interesting trends have been revealed. Women consistently use the crossings more than men; the children have the best record of all. At Slough, the zebra crossing had the effect of raising the index for males from 63·9 to 70·3 and for females from 80·8 to 84·9; the proportion of cars that stopped at the crossing also showed a significant increase.

The mechanical properties of vehicles are also studied from the safety aspect, particular attention being devoted to brakes and steering.

With the co-operation of the police, brake tests are carried out on vehicles stopped on the road, few drivers refusing to submit to the tests. In terms of braking distance (distance covered after the driver has put his foot on the brake pedal), the best result obtained—actually with the Laboratory's own car under optimum conditions—was a stopping distance of 45 ft. at 30 miles per hour. Some cars take 100 ft. at the same speed; the average distance is about 70 ft. Buses and 5-ton lorries travel 75 ft. before stopping, while heavy lorries with loaded trailers can only manage to stop within 70 ft. at 20 miles per hour. The braking performance of old cars (of 1936 vintage or older) was not significantly inferior to that of new models.

The 'reaction time' of drivers varies considerably, about 50% of the drivers observed taking 0·6 seconds or longer to apply the brake and 20% of them more than a second. Taking both driver's reaction and braking efficiency into account, 90% of the vehicles on the road would be unable to stop from 30 miles per hour in 55 ft., and 20% in 150 ft.

To find out how people are behaving on the road at night observers have counted the numbers of undipped headlights, dipped headlights, pass-lamps used, etc., and have made a subjective estimate of dazzle. It was found that even on unlighted roads only 15% of drivers used their full headlights and only about a third of those who used headlights refused to dip. About 80% of the drivers encountered used either some kind of dipped beam or a pass-lamp intended to cut down dazzle. About 10% drove with side lights only. It was also noted that low-mounted pass-lamps were twice as likely to cause dazzle as dipped head-lamps. This was the reason for the regulation introduced early last year, which provides that pass-lamps must be at least 2 ft. from the ground.

A survey of vehicles carried out last winter revealed that over 16% of cyclists in country areas and over 12% in built-up areas had no rear lights, the figure for cars being about 3% and for motor cycles $3\frac{1}{2}$%. Since 10% of motorists are driving with side lights only, a very dangerous hazard is thus created.

The use of polarised lights is a possible means of overcoming the dazzle problem and would avoid the necessity for dipping lights. To make this system effective all cars would have to have their headlamps fitted with a polariser and drivers would require an analyser screen treated in the same manner. By these means the light from approaching headlamps would be cut out by the analyser, while objects illuminated by his own lamps would remain visible to the driver.

But various difficulties prevent this desirable solution from being readily achieved. One arises from the fact that the polarising material absorbs more than half of the light that falls on it, which would make it necessary to use lamps about $3\frac{1}{2}$ times more powerful than those ordinarily used.

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